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Controlling non-conformity propagation in low volume manufacturing

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To my grandparents,
I am everything I am
because you loved me.
I wish you were there.

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ACRONYMS

3K: kiken (dangerous), kitanai (dirty), and kitsui (stressful) in reference to perception of the shopfloor
ARL: Average Run Length
ATS: Average Time to Signal
B-to-B: Business to Business
CIFRE: Convention Industrielle de Formation par la Recherche en Entreprise
ERP: Entreprise Resource Planning
E T HS: Energy Transmission High-voltage Substation
I A SC: Industry Automation Sensor and Communication
JIT: Just-in-time
NC: Non-conformity
OM: Operation Management
QCD: Quality-Cost-Delay
REX: Return on experience
RQ: Research question
SM: Managed Safety
SC: Controlled Safety
SPC: Statistical Process Control
SPS: Siemens Production System
TPS: Toyota Production System
TQC: Total Quality Control
TQL: Total Quality Learning
TQM: Total Quality Management
VSM: Value Stream Mapping

LA THESE EN FRANÇAIS

Cette section présente un résumé étendu de la thèse en français. Elle est indépendante du reste de la thèse.

TITRE

Maitrise de la propagation des non-conformités en fabrication dans l'industrie de faible volume.

RESUME

Ce travail de thèse propose une approche pluridisciplinaire de la qualité dans les systèmes de production manufacturiers, couplant les approches d'ingénierie et de sociologie des organisations. Il s'intéresse aux risques de non-conformités qui peuvent se propager dans le processus de réalisation et atteindre le client final. Il est basé sur des études de cas réalisées chez Siemens E T HS (Energy Transmission High-voltage Substation), une entreprise produisant de faibles quantités de matériel haute-tension hautement personnalisé. Il propose tout d'abord une méthode qualité pour améliorer le système de détection des non-conformités en identifiant et en agissant sur ses faiblesses. Dans une deuxième approche, cette thèse propose des instruments organisationnels pour limiter la propagation des non-conformités entre les frontières organisationnelles et améliorer la résilience de l'organisation face à ces problèmes transfrontières. Les deux approches ont été mises en œuvre dans l'entreprise étudiée puis étendues à une autre entreprise du groupe opérant sur le segment de la production de masse ce qui a permis de tirer des conclusions à la fois académiques et managériales pour les partenaires industriels.

MOTS CLES

Qualité, Production de faible volume, Propagation, Non-conformités, Transfrontière, Résilience organisationnelle

Chapitre 1 Introduction

1.1 Contexte académique

La performance industrielle est un enjeu majeur pour les entreprises depuis le début de l'ère industrielle. Son évaluation a cependant évolué d'un simple indicateur de productivité à une évaluation multicritères prenant en compte à la fois le triangle classique couts-qualité-délai mais aussi des critères de flexibilité, de performances sociale et environnementale et de fiabilité. Cette évolution vers des problématiques socio-économiques induit un besoin de recherche interdisciplinaire, particulièrement dans le domaine de la gestion des risques industriels. Les risques industriels sont définis par (Magne and Vasseur, 2006) comme des risques qui doivent être pris en compte par les organisations qui construisent, exploitent et contrôlent des installations industrielles. Cette notion englobe à la fois les risques de défaillance et les risques économiques.

Parmi ces risques industriels, ce travail de thèse s'intéresse au risque de non-conformités en fabrication qui peuvent atteindre le client final. Ces risques questionnent la performance du système de protection de l'entreprise, i.e. les différents mécanismes mis en œuvre par l'entreprise pour se protéger contre les risques : d'un côté les analyses de risques pour éviter l'occurrence des défauts, de l'autre le système de détection pour détecter les défauts au plus vite.

Le concept des barrières de protection (Summers, 2003; Sklet, 2006; Hollnagel, 2008; Duijm, 2009) surtout utilisé dans le domaine de la sureté industrielle, illustre les efforts pour éviter la propagation des non-conformités et les stopper le plus près possible de leur origine. Bien que la prévention soit la plupart du temps préférable à la protection, une prévention totale est impossible. Dans cette perspective, les approches récentes sur les risques et sur la résilience organisationnelle présentent les variations et les dégradations des conditions de travail comme des composantes quotidiennes de la vie des organisations (Weick, 2001; Hollnagel and Woods, 2006; Barton and Sutcliffe, 2009). Ce renversement des perspectives classiques de maitrise des risques permet de définir la fiabilité non pas par l'absence d'événement imprévu et de variation, mais par la capacité de l'organisation de prendre en charge les irrégularités, les problèmes, et les dégradation des conditions de travail, et de faire face aux dangers non-anticipés et aux incertitudes.

Le concept de perméabilité des barrières de protection doit être adapté au contexte des productions de faibles volumes, dans lesquelles on ne peut pas se permettre d'attendre qu'une défaillance se reproduise pour agir.

1.2 Contexte industriel

Cette thèse a été conduite avec un partenaire industriel sur la base d'une convention CIFRE. Le partenaire impliqué dans le projet est Siemens E T HS à Grenoble, filiale de Siemens AG spécialisée dans le développement et la fabrication d'appareillages électriques haute-tension. Les clients de Siemens E T HS sont principalement les entreprises gestionnaires des réseaux électriques. L'entreprise propose à ses clients des produits personnalisés, et fonctionne sur le mode « engineering-to-order ». Siemens E T HS appartient à l'industrie de faible volume qui a les caractéristiques suivantes :

- marché B-to-B (visant une clientèle d'entreprise, i.e. les compagnies nationales d'électricité)
- production en «make-to-order» ou «engineering-to-order»
- produits à forte valeur ajoutée
- inspections à 100% (risques sécurité)
- contraintes de traçabilité importantes (normes)

Selon (Jina et al., 1997), ces industries font face à plus de turbulences que les autres industries. De plus, les méthodes et outils utilisés dans la production de masse, ne peuvent pas être transposés en l'état au contexte des faibles volumes, particulièrement dans le domaine de la qualité pour lequel les outils statistiques ne semblent pas adaptés. Une étude bibliographique n'a pas permis de trouver des travaux concernant la performance industrielle, ou la qualité en fabrication dans ce type de contexte. Ce travail de thèse s'intéresse donc à cette lacune, et a pour but de répondre à la question suivante : Comment la performance et la résilience d'un système de production de faibles volumes peuvent-elles être caractérisées, mesurées et améliorées ? Cette question se fonde sur une étude bibliographique et sur la situation industrielle de l'entreprise étudiée qui sera détaillée dans le chapitre 2.

1.3 Plan de la thèse

La thèse est structurée comme suit. Le chapitre 2 présente la formulation de la question de recherche, en montrant comment elle a émergée conjointement entre les partenaires industriel et académique. Le chapitre 3 positionne notre travail dans la littérature concernant la qualité, la résilience organisationnelle et la fiabilité. Le chapitre 4 détaille la méthodologie de recherche et les différentes phases du projet. Ensuite, le chapitre 5 présente notre proposition pour l'amélioration du système de protection des entreprises industrielles. Cette proposition est composée d'un outil qualité et de mesures organisationnelles favorisant la collaboration aux frontières de l'organisation. Le chapitre 6 présente la mise en œuvre des propositions dans deux entreprises du groupe Siemens. Enfin le chapitre 7 conclut sur le travail effectué et propose des perspectives de recherches futures.

Chapitre 2 Formulation des questions de recherche

2.1 Motivation

La motivation de ce travail de thèse a émergé conjointement des partenaires industriels et du laboratoire de recherche. L'entreprise était régulièrement confrontée à des non-conformités provenant de toutes les étapes du processus de réalisation et qui parfois atteignaient le client final induisant des couts très élevés en terme de reprise et d'image. Le sentiment interne était que ces problèmes pouvaient provenir soit : i) d'un système qualité inadapté soit ii) des barrières entre les entités organisationnelles qui empêchent une résolution pérenne des problèmes. Pour l'entreprise, il y avait un intérêt à conduire une analyse transverse des causes de défaillance. D'un point de vue académique, ce travail de thèse constituait une opportunité de conduire une analyse de la performance des systèmes qualité *in situ* dans le contexte peu étudié des industries de faible volume et de grande variabilité de produits. Les questions de recherche ont été définies et affinées durant les réunions trimestrielles du comité de pilotage du projet, constitué d'une équipe pluridisciplinaire composée de chercheurs sur la performance industrielle, le processus contrôle et la sociologie des organisations ainsi que de professionnels de la qualité, de l'amélioration continue et du directeur de l'usine.

2.2 Diagnostic

La première étape du projet de recherche a été un diagnostic de l'organisation qui a permis au chercheur de se familiariser avec l'entreprise et le processus de fabrication. L'entreprise travaille en mode projet. Elle développe et fabrique des équipements personnalisés selon les besoins de ses clients. Le processus de réalisation est divisé en différentes activités qui correspondent à des équipes différentes, ce qui induit un besoin de coordination. La complexité du produit ainsi que le niveau élevé de personnalisation entrainent de nouvelles incertitudes pour chaque activité et pour chaque projet.

2.2.1 Le système qualité existant

L'usine est divisée en deux lignes de production et une ligne de préfabrication. L'organisation qualité de l'entreprise repose sur différentes entités (qualité fournisseur, inspection d'entrée, qualité ligne, qualité fabrication, qualité système, qualité projet) pour un total de 25 experts qualité. Le processus de traitement des non-conformités est donné en annexe VI. Il distingue les non-conformités liées aux fournisseurs externes et les non-conformités générées en interne ainsi que les non-conformités mineures et majeures. L'entreprise a également entrepris fin 2009 une démarche Lean dont l'amélioration de la qualité est un des objectifs majeurs.

2.2.2 Les différents types de problèmes qualité

L'immersion opérationnelle ainsi que l'analyse des rapports qualité montrent que l'entreprise est régulièrement confrontée à des défaillances qui perturbent le flux de production. On peut dire que l'entreprise a une activité «normalement perturbée ». Un total de 616 rapports qualité ont été émis en 2009 pour 430 produits fabriqués par les deux lignes de production, dont 75% après livraison, principalement durant l'installation sur site. Cela illustre le problème de propagation auquel est confronté l'entreprise.

La répartition de ces problèmes est la suivante : 37% proviennent de l'assemblage en usine, 30% de la conception et 17% des fournisseurs externes. Les 16% restants regroupent le transport et la manutention, la peinture et l'installation sur site. Concernant les problèmes d'assemblage, plus de la moitié sont dus à des informations manquantes ou peu claires, particulièrement au niveau des documents de montage.

2.2.3 L'origine des problèmes qualité

L'analyse des rapports qualité et l'observation directe ont permis de mettre en évidence les causes profondes des problèmes :

- des barrières aux frontières organisationnelles, particulièrement entre la production et les services supports
- des flux d'information peu efficaces et un manque de réactivité
- des faiblesses au niveau des documents de montage (mise à jour, cohérence, clarté)
- des faiblesses dans la formation technique
- un manque de vigilance
- des rectifications informelles par le couple opérateur-chef d'équipe.

2.2.4 La gestion des problèmes qualité

Comme dans toutes les organisations, des rattrapages permettent d'éviter des accidents et des crises. Deux étapes ont été observées dans la gestion des problèmes : une gestion locale par l'opérateur et le chef d'équipe et une gestion transfrontière par le chef d'équipe qui va contacter d'autres acteurs pour résoudre son problème, mais pas forcément dans le cadre du processus formalisé de résolution de problème géré par les équipes qualité. En dépit de tous les filtres mis en place par l'organisation et de l'implication permanente des chefs d'équipes, certains problèmes ne sont pas rattrapés et vont conduire à un arrêt de production ou à un problème détecté chez le client. Ces incidents ne sont pas très différents de ceux qui sont rattrapés. En effet, la détection se fait souvent par chance en dehors des contrôles formalisés. De plus ils peuvent être dus à des corrections locales et informelles dont les conséquences ne sont pas maitrisées.

Enfin, ces incidents peuvent conduire à des désastres s'ils se propagent jusqu'au client final.

Quand ce travail de thèse a été initié, l'entreprise faisait face à une série d'incidents qualité sérieux. Elle était dans une situation de crise par accumulation. Ces incidents ont généré un sentiment interne d'incertitude quant à la maitrise et à la fiabilité du processus de réalisation.

2.3 Questions de recherche

Ces premières observations de la gestion des problèmes qualité questionnent la performance des mécanismes de détection en place. Nous proposons donc d'étudier deux dimensions de la performance des systèmes de protection dans le contexte de faibles volumes de production. Tout d'abord, dans une perspective de contrôle qualité, nous proposons d'étudier le système de détection des non-conformités.

RQ 1 : Comment peut-on caractériser la performance du système de protection en industrie de faible volume ?

- Quelles sont les particularités du management de la qualité dans ce contexte ?
- Quels outils et méthodes sont adaptés ?
- Ces outils sont-ils adaptés à d'autres industries ?

Nous avons également identifié que dans les environnements « normalement » perturbés, les activités de « passage de frontière » *(boundary spanning activities)* et la résilience de l'organisation sont nécessaires pour assurer la continuité de l'activité et éviter que les non-conformités se propagent.

RQ 2 : Quels types de dispositifs organisationnels peuvent favoriser la résilience et la transversalité dans les situations de résolution de problème ?

- Dans quelle mesure les objets et les individus transfrontières peuvent-ils être des piliers de la résilience ?
- Quelles méthodes et outils peuvent favoriser la communication et la collaboration entre les services concernant les problèmes qualité et leur résolution ?

Chapitre 3 Revue de la littérature

3.1 Introduction : La gestion des problèmes qualité, un besoin de détection au plus tôt

Les entreprises, les régulateurs, les investisseurs et les consommateurs reconnaissent que les rappels de produits sont des composantes inévitables de la conduites des affaires (Berman, 1999). Même les entreprises qui portent des efforts importants sur la qualité et l'amélioration continue peuvent être touchées par ce type d'événement. Cependant la littérature sur le sujet s'intéresse principalement à la gestion des retours (logistique inverse, politique de remboursement, assurance, etc.) mais donne peu de pistes sur la manière de les éviter. Cette question renvoie au mécanisme de propagation du défaut.

Un concept intéressant lié à la propagation a été trouvé dans le domaine de la sureté de fonctionnement, i.e. le concept de barrières de protection (Reason, 1990; Sklet, 2006; Hollnagel, 2008). Ces barrières de protection sont des moyens physiques ou immatériels prévus pour prévenir, contrôler, atténuer les événements non-désirés et les accidents. Elles illustrent les efforts pour éviter la propagation des problèmes en les stoppant le plus près possible de leur origine pour limiter leur impact. Dans le domaine de la qualité, ces barrières de protection peuvent être des cartes de contrôle, des tests d'acceptation, de la maintenance préventive, des détrompeurs, des procédures, etc.

La littérature a été analysée pour trouver des outils et des méthodes qui pourraient contribuer à la détection au plus tôt des défaillances dans le contexte des industries de faible volume. Des contributions intéressantes ont été trouvées à la fois dans la littérature en qualité et en sociologie des organisations. Cette revue bibliographique est structurée autour de ces deux dimensions.

3.2 La qualité en fabrication

3.2.1 Développement du TQM - concepts généraux

Le management de la qualité totale (TQM) connait un succès considérable dans les entreprises et a fait l'objet de beaucoup d'études ces dernières années. Même si les considérations qualité sont apparues au début du 20ème siècle (Shewhart, 1931), et se sont diffusées après la seconde guerre mondiale, c'est seulement dans les années 90 que les entreprises aux Etats-Unis et en Europe ont commencé à les mettre en œuvre (Sitkin et al., 1994). Avant le développement du TQM, les efforts qualité étaient principalement orientés vers le contrôle. L'évolution vers le TQM a été motivée par la mise en évidence du fait que les questions de qualité doivent prendre en compte le système socio-économique et inclure les clients et les employés dans ce type de démarche. La théorie du management de la qualité a été tout d'abord influencée par les contributions des pionniers de la qualité (Feigenbaum, 1982; Ishikawa and Lu, 1985; Deming, 1986;

Garvin, 1986; Juran, 1988; Crosby, 1995). Selon (Tarí and Sabater, 2006), le TQM est une stratégie qualité qui a pour but d'augmenter la différentiation et de réduire les couts. Le TQM se compose de différents éléments qui peuvent être regroupés en deux catégories : le système de management (culture qualité, orientation client, implication des employés) et le système technique (outils statistiques, juste-à-temps, etc). Depuis deux décennies, des approches encore plus globales comme le Lean Manufacturing se sont développées et intègrent dans leurs pratiques les aspects du TQM.

3.2.2 Les pratiques qualité pertinentes dans le contexte des faibles volumes

Beaucoup de travaux souscrivent à la théorie de l'universalité de l'application du TQM (Deming, 1986; Juran, 1988; Crosby, 1995). En conséquence, le TQM risque d'être utilisé de manière inappropriée et inefficace. Cela explique les nombreux échecs dans la mise en œuvre du TQM.

Beaucoup d'études ont analysé les facteurs critiques de mise en œuvre des pratiques qualité et leur influence sur la performance. Parmi les principes clés du TQM, certains sont particulièrement pertinents dans le contexte des faibles volumes. Ils sont détaillés ci-dessous.

- *Orientation client* : amélioration continue des processus pour mieux satisfaire les besoins des clients internes et externes
- *Orientation Qualité* : attention permanente à la qualité à tous les niveaux de l'organisation, depuis la direction jusqu'aux opérateurs
- *Leadership* : les managers sont des pilotes de la mise en œuvre des principes qualité
- *Formation* : formations techniques tournées vers la polyvalence et formations non-techniques sur les méthodes et outils qualité
- *Outils qualité* (SPC, Six Sigma, diagramme de Pareto, diagramme d'Ishikawa) : Les outils statistiques ne sont pas adaptés au contexte des faibles volumes car les temps de cycles longs et les faibles quantités de produits ne permettent pas d'utiliser les méthodes SPC ou Six Sigma.
- *Pratiques Lean*
    - Management terrain : le principe du management terrain est de chercher les données réelles directement sur le terrain. Toutes les réunions concernant l'atelier se font sur le terrain
    - Management visuel et transparence : rendre les informations visibles pour les opérateurs et les managers
    - Jidoka : stopper la production en cas de problème
    - Culture et méthode de résolution de problème : corriger immédiatement les problèmes en suivant une démarche structurée

3.2.3 Conclusion

Cette revue des méthodes qualité en production a permis de mettre en évidence des outils et méthodes adaptés au contexte des faibles volumes. Cependant, aucune de ces méthodes ne prend en compte la rapidité et la performance de détection des problèmes, ni la capacité de l'organisation à maintenir un fonctionnement acceptable en cas de problème. Des contributions intéressantes dans ce domaine ont été trouvées en sociologie des organisations et sont présentées dans la partie suivante.

3.3 Gestion des risques transfrontières

Le terme risque transfrontière renvoie à la diversité de lieux où peuvent se produire les déviations, à la propagation possible de ces déviations à travers les différentes étapes du processus de réalisation et au travail de ré-articulation effectué par les personnes impliquées dans la rectification des incidents.

3.3.1 La division du travail crée des incertitudes, des aléas et des défaillances

Les activités sont segmentées, ce qui peut crée des incohérences et des pertes d'information. Les études ethnographiques de (Strauss, 1988; Star and Griesemer, 1989) ont montré à quel point la coordination entre différents mondes sociaux ou communautés de pratiques peut être difficile. Pour surmonter cette difficulté il est possible d'avoir recours à des objets ou des individus transfrontières (Star and Griesemer, 1989; Carlile, 2002).

3.3.2 Les aléas font partie du quotidien des organisations, la fiabilité est d'y faire face

L'étude de situations normalement perturbées et de situations de crises, dans lesquelles le sens s'effondre (Weick and Roberts, 1993) est particulièrement intéressante pour identifier les conditions de la résilience organisationnelle.

3.3.3 Résilience organisationnelle

La résilience est la capacité d'une organisation ou d'un système à garder ou à retrouver un état de stabilité qui lui permette de maintenir un fonctionnement acceptable pendant et après un incident majeur ou en présence d'un stress continu (Hollnagel et al., 2006). Parmi les propriétés des organisations résilientes, nous avons identifié dans la littérature la correction immédiate des déviations (Wreathall, 2006), l'anticipation et la préparation (Weick and Sutcliffe, 2001), l'improvisation (Rerup, 2001) et la flexibilité (Hollnagel et al., 2006).

Plusieurs propositions pour améliorer la résilience des systèmes complexes ont été trouvées dans la littérature : i)fournir à l'organisation des marges de manœuvre encadrées pour improviser en temps de crise (Rerup, 2001; Adrot and Garreau, 2010) ii) développer des savoir-faire face à des situations déstabilisantes grâce à des scénarii d'anticipation et des simulations (Morel et al., 2008) iii) développer la conscience des situations par des formations aux métier des autres acteurs (*cross-training*) iv) éliminer du système les processus et artefacts qui peuvent conduire à des dysfonctionnements.

3.3.4 *Traverser les frontières pour réarticuler le travail et créer un point de vue multi-situé*

Le travail d'articulation peut être pris en charge par des individus transfrontières ou par des objets frontières qui permettent le partage de langage et de sens ainsi que l'alignement des pratiques. (Star and Griesemer, 1989) ont développé le concept d'objet frontière pour analyser la nature du travail coopératif en l'absence de consensus. La notion d'individu transfrontière provient des travaux de (Tushman and Scanlan, 1981a). Ces individus sont des ressources efficaces pour collecter et transférer des informations entre les frontières organisationnelles.

3.3.5 *Conclusion*

Le concept de résilience est en plein développement, particulièrement dans le domaine de la sureté de fonctionnement. Même si le concept tend à s'élargir vers d'autres domaines, peu de travaux ont été retrouvés concernant une application de la résilience au champ de la qualité en fabrication, dans lequel on pourrait considérer la résilience comme la capacité d'une organisation à faire face aux défaillances altérant ses produits ou processus, et à maintenir un niveau de qualité acceptable en dépit des problèmes qualité et des crises. Le concept est particulièrement adapté au cas des faibles volumes, dans lequel la flexibilité et l'adaptation sont des composantes importantes des projets. Les objets et les individus transfrontières peuvent être des piliers de la résilience organisationnelle. Cependant peu de travaux ont été trouvés concernant les limites de ces mécanismes.

Chapitre 4 Méthodologie

4.1 Choix de l'approche

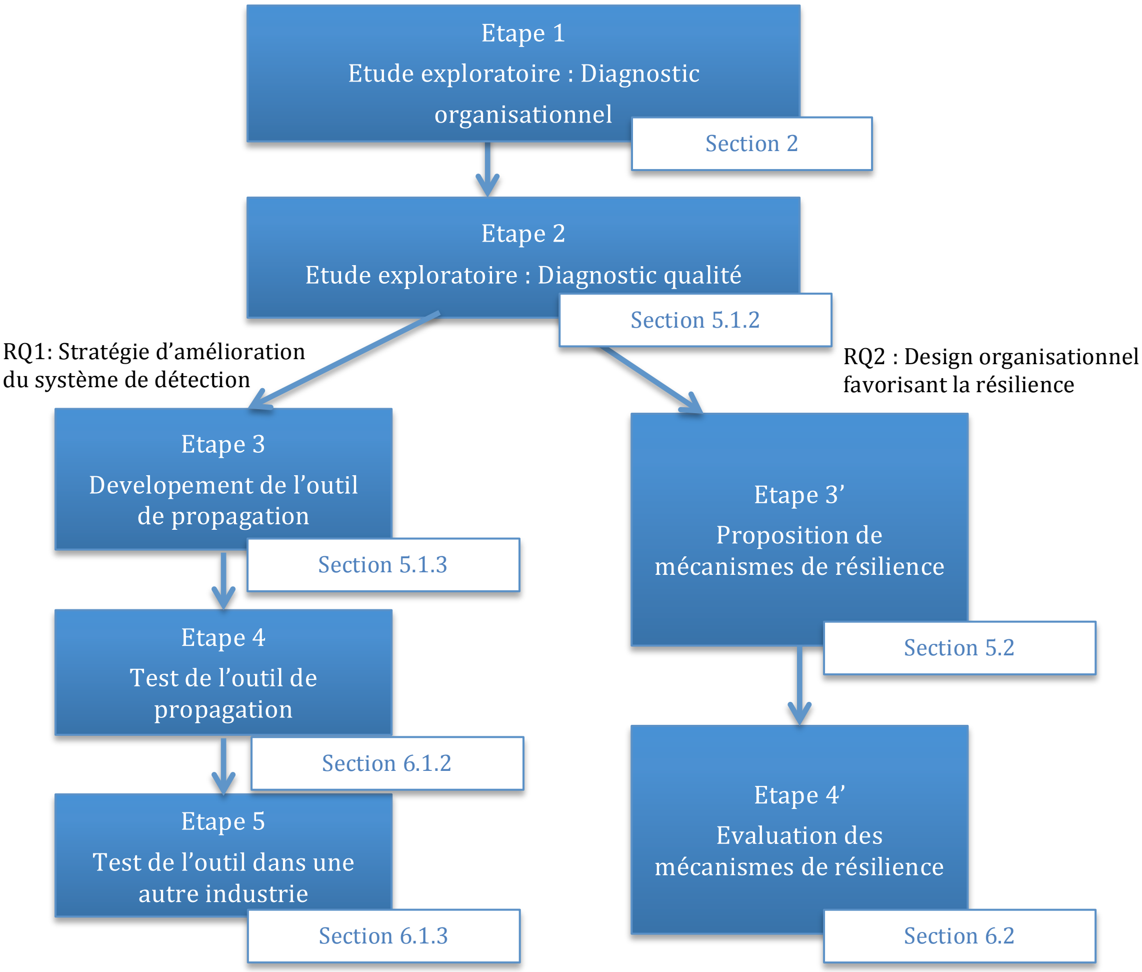
La méthode adoptée dans le cadre de ce projet de recherche est l'étude de cas. Cette approche est adaptée à notre projet car :

- Elle permet d'étudier un phénomène dans son contexte industriel et de générer des connaissances généralisables à partir d'observations de la pratique (Eisenhardt and Graebner, 2007).
- Elle permet de répondre à des questions de type « quoi/ quel ? » et « comment ?»
- L'implication du chercheur dans l'entreprise étudiée permet l'accès aux données et des interactions avec les participants.

Le projet a été conduit comme un enchainement d'études de cas longitudinales. On peut le qualifier de recherche clinique puisque les observations sont conduites *in situ*.

4.2 Protocole de recherche

Le projet a été décomposé en cinq phases qui ont été conduites de manière séquentielle ou en parallèle.



Les différentes phases du projet de recherche

Un résumé des différentes phases du projet est donné dans le tableau ci-dessous.

	Etape 1	**Etape 2**	**Etape 3**	**Etape 4**	**Etape 5**
Localisation	Grenoble	Grenoble	Grenoble	Grenoble	Haguenau
Durée	Oct.-Nov. 2009 (2 mois)	Avril 2010 (1 mois)	Mai-Oct. 2010 (6 mois)	Mars- Juil. 2011 (4 mois)	Dec. 2011-Jan. 2012 (2 mois)
Statut du chercheur	Participant qui observe	Participant qui observe	Participant complet	Participant complet	Observateur qui participe
Type d'étude	Longitudinale	Longitudinale	Rétrospective	Longitudinale	Longitudinale
Objectif	*Exploratoire* Premier diagnostic de l'entreprise sur le thème de la gestion des non-conformités	*Exploratoire* Analyse des contrôles qualité (pourquoi y a t-il de la propagation ?)	*Création de connaissance* Conception d'un outil qualité pour maitriser la propagation	*Test de théorie* Validation de la pertinence de l'outil sur une étude en temps réel	*Test de théorie* Généralisation de l'outil
Méthode et sources des données	Investigation terrain, observation directe, interviews (20)	Observation directe et interviews	Analyse rétrospective des problèmes qualité d'une année (analyse des rapports et interviews)	Analyse en temps réel des non-conformités (analyse des rapports et implication dans la résolution)	Analyse en temps réel des non-conformités (observation directe et interviews)
Résultats	Définition de la question de recherche et du cadre de recherche	Cartographie des contrôles Identification des faiblesses et potentiels d'amélioration	Définition de l'indicateur de propagation et de l'outil de propagation	Validation et affinement de l'outil dans le cas des faibles volumes	Validation et affinement de l'outil dans le cas des volumes élevés

Résumé des phases du projet de recherche

Les étapes 3' et 4' ne figurent pas dans le tableau mais reposent principalement sur l'immersion opérationnelle du chercheur à travers l'animation de formations au Lean Manufacturing et de groupes de travail interdisciplinaires.

4.3 Evaluation du projet de recherche

La validité du projet de recherche est évaluée grâce à plusieurs concepts : la fiabilité, la validité des concepts, la validité interne et la validité externe (Stuart et al., 2002). Les indicateurs retenus pour évaluer nos propositions sont les couts de non-qualité, les temps de cycles, la distance de propagation, la réactivité et la pérennité dans la résolution de problème.

Chapitre 5 Proposition

5.1 Stratégie d'amélioration pour le système de détection

L'objectif du système de contrôle qualité est de détecter et de stopper les non-conformités le plus tôt possible. Une opportunité existe pour adapter le concept de moyen de protection utilisé en sureté de fonctionnement au domaine de la qualité dans les industries de faible volume. L'objectif de cette partie est donc de proposer des outils pour mesurer et améliorer la performance des systèmes de protection. Nous proposons de répondre à la question suivante :

RQ 1 : Comment peut-on caractériser la performance du système de protection en industrie de faible volume ?

5.1.1 Première approche : cartographie des contrôles qualité

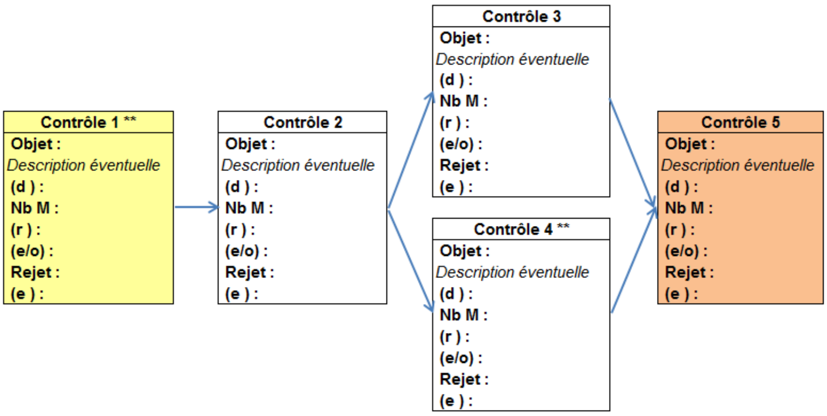
L'objectif est d'analyser la valeur ajoutée des contrôles qualité pour les rationnaliser et identifier les brèches, i.e. les endroits dans le processus où les contrôles sont inexistants ou inefficaces. Cette étude conduit à une cartographie des contrôles pour analyser la cohérence globale du plan de contrôle.

5.1.1.1 Approche méthodologique

Les données ont été recueillies par des observations directes pendant un mois sur la ligne d'assemblage et par des interviews des opérateurs (20). Une base de données Excel a été construite pour enregistrer les données.

5.1.1.2 Proposition de cartographie

Aucune proposition de cartographie des contrôles n'a été trouvée dans la littérature. L'inspiration pour cette cartographie provient de la méthode VSM (Cartographie de la chaine de valeur). Pour chaque opération les contrôles sont représentés comme des flux pour prendre en compte les contraintes de précédence (voir Figure ci-dessous).



Séquence de contrôles pour une opération

]

La cartographie des contrôles pour tout le processus d'assemblage est donnée en annexe.

5.1.1.3 Résultats

La cartographie présentée donne une vue d'ensemble du plan de contrôle dans le but d'identifier les gaspillages et les potentiels d'amélioration. Elle va permettre de mettre en évidence les différences entre la théorie et la réalité des pratiques terrain, la proportion de contrôles formalisés et non formalisés, la quantité et la durée des contrôles par opération, les redondances.

Dans le cas présenté, la cartographie a permis d'analyser les mécanismes de contrôle d'une industrie de faible volume et d'en déduire les caractéristiques suivantes : la redondance, le fait que le plan de contrôle doit être ajusté de manière incrémentale, que les contrôles ne soient pas complètement documentés mais qu'ils reposent en partie sur le savoir-faire des opérateurs et qu'ils représentent, en termes de charge, une part importante du travail des opérateurs.

La difficulté dans l'analyse de la cartographie réside dans la quantification de la valeur ajoutée des contrôles. Cette valeur ajoutée est liée à l'efficacité des contrôles. Pour évaluer cette valeur ajoutée, nous proposons une stratégie de contournement consistant à évaluer la perméabilité des contrôles ou des opérations du processus d'assemblage. La perméabilité correspond au nombre de problèmes non-détectés pour un contrôle ou une opération donnée. La perméabilité est liée à la propagation des défauts qui est définie comme la distance, en nombre d'étapes dans le processus, parcourue par un défaut avant d'être détecté.

La cartographie ne prend en compte qu'un type de barrière de protection, les contrôles qualité. La partie suivante propose d'élargir l'étude de la propagation en prenant en compte d'autres mécanismes de protection comme les formations, les détrompeurs, les procédures, etc.

5.1.2 Seconde approche : modèle de propagation et méthode d'amélioration

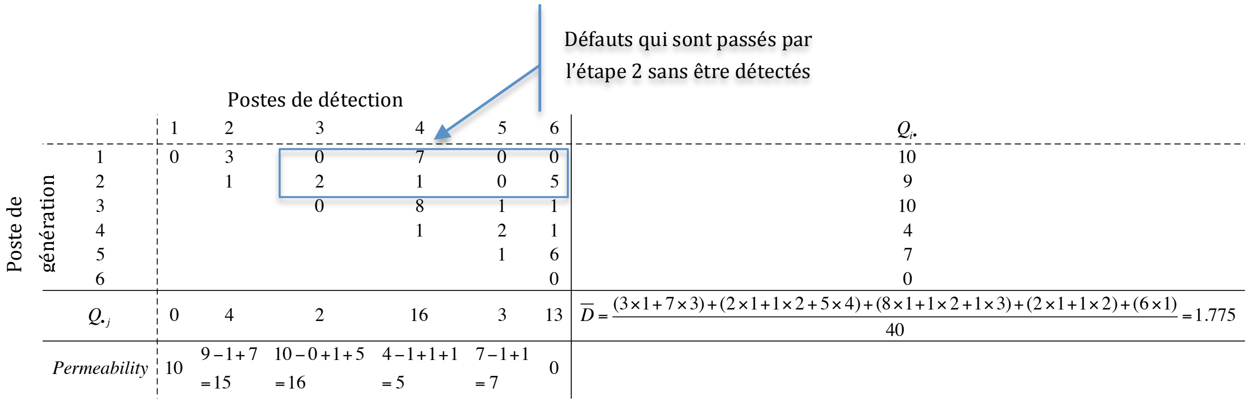
L'objectif de cette approche est d'évaluer les distances de propagation des non-conformités sur la ligne de fabrication étudiée pour valider la pertinence de l'indicateur de propagation et de présenter une méthode pour maitriser cette propagation.

5.1.2.1 Approche méthodologique

Les données proviennent de l'analyse de 41 rapports de non-conformités édités en 2009 sur la ligne étudiée. Elles ont été complétées par des interviews des équipes qualité. Le processus d'assemblage a été décomposé en 15 opérations et la distance de propagation a été calculée pour chaque défaut. La distance moyenne de propagation atteint six étapes, soit 40% de la longueur du processus.

5.1.2.2 Proposition

Une stratégie à deux niveaux est proposée pour diminuer la distance de propagation. Elle comprend un niveau « système » et un niveau « événement ». Au niveau « système », la méthode consiste à enregistrer les distances de propagation pendant une période donnée dans une matrice de propagation croisant les postes de génération et de détection des défauts. Elle va permettre d'analyser la perméabilité des opérations et de diriger les actions d'amélioration vers les opérations les plus perméables. Les sommes en ligne et en colonne ($Q_{i.}$ et $Q_{.j}$) donnent respectivement les quantités de générations et de détections de défauts par opération sur la période. Cette matrice est présentée ci-dessous.



Défauts qui sont passés par l'étape 2 sans être détectés

Postes de détection

Poste de génération

	1	2	3	4	5	6	$Q_{i\bullet}$
1	0	3	0	7	0	0	10
2		1	2	1	0	5	9
3			0	8	1	1	10
4				1	2	1	4
5					1	6	7
6						0	0
$Q_{\bullet j}$	0	4	2	16	3	13	$\overline{D}=\frac{(3\times1+7\times3)+(2\times1+1\times2+5\times4)+(8\times1+1\times2+1\times3)+(2\times1+1\times2)+(6\times1)}{40}=1.775$
Permeability	10	$9-1+7=15$	$10-0+1+5=16$	$4-1+1+1=5$	$7-1+1=7$	0	

Matrice de propagation

Au niveau « événement », la méthode consiste en une analyse en temps réel de la propagation de chaque défaut grâce à une carte de contrôle. Les actions d'amélioration sont déclenchées en cas de dépassement d'un seuil de propagation et basées sur l'analyse du chemin de propagation pour chaque défaut.

5.1.2.3 Conclusion

La stratégie à deux niveaux présentée pour maitriser la propagation des non-conformités constitue une méthode d'aide à la décision qui met en évidence les faiblesses du système de protection et localise les opportunités d'amélioration. Cette méthode est destinée aux équipes qualité qui ont en charge de la mettre en œuvre. Un test de la méthode est présenté au chapitre 6.

5.2 Quels mécanismes organisationnels pour favoriser la résilience et la résolution des problèmes transfrontières ?

5.2.1 Objectif

Comme expliqué au chapitre 2, l'analyse des incidents qualité montre que les non-conformités se propagent entre les frontières organisationnelles. Ce type de défaut induit des situations de résolution de problèmes transverses. Ces situations sont aussi un bon point d'entrée pour améliorer la coordination et la communication. L'objectif de cette partie est de proposer des mécanismes organisationnels pour assurer la continuité de l'activité aux frontières entre univers professionnels disjoints dans les situations de résolution de problème et mieux faire face aux événements non-désirés. Cet objectif est résumé dans la deuxième question de recherche :

RQ 2 : Quels types de dispositifs organisationnels peuvent favoriser la résilience et la transversalité dans les situations de résolution de problème ?

5.2.2 Méthode

La méthode utilisée est l'immersion opérationnelle dans l'entreprise étudiée, à travers l'animation de 40 sessions de formation au Lean Manufacturing et de différents groupes de travail sur les problèmes d'assemblage et de documents. L'objectif était de collecter des données sur les problèmes qualité et les dysfonctionnements dans l'articulation entre les différents services. Ces données ont été complétées par des interviews et par l'analyse d'une cinquantaine de rapports qualité formels.

5.2.3 Les individus transfrontières : un pilier de la résilience ?

5.2.3.1 Des individus flexibles et astucieux qui réarticulent le travail aux frontières

Dans l'entreprise étudiée, les défaillances de coordination entre les services sont depuis longtemps compensées et rattrapées par les chefs d'équipes qui facilitent la circulation des informations pour assurer la continuité de la production. Ces individus flexibles et « bricoleurs » permettent de rattraper la plupart des déviations et sont donc une source importante de résilience.

5.2.3.2 Les limites d'une résilience basée uniquement sur ces individus

Les chefs d'équipes agissent principalement dans l'urgence, comme des pompiers. Mais un excès de flexibilité peut en cas de crise leur faire perdre le contrôle. Le chef d'équipe est débordé par son rôle de passeur de frontière et les sollicitations qui lui parviennent de toutes parts, ce qui le rend moins vigilant, et augmente sa fatigue et son stress.

De plus, la légitimité du chef d'équipe est limitée face aux différents services supports. Il n'a pas la capacité de faire entendre sa perception des risques, particulièrement lorsqu'il sollicite l'intervention d'un service support. Enfin, il n'a pas nécessairement la capacité de détecter toutes les déviations, car il n'a pas une vue globale du projet et sous-estime parfois l'impact de ses actions correctives isolées, qui peuvent se transformer en non-conformité à l'échelle globale. Le chef d'équipe, comme tous les autres acteurs, cherche à atteindre un optimum local, celui de son équipe, qui peut être très différent de l'optimum global de l'organisation. Dans certains cas il n'a pas toute l'expertise technique nécessaire pour prendre une décision.

5.2.3.3 Le recours à des tiers pour rétablir de l'ordre et de la cohérence dans la gestion des crises

Dans le cas présenté, l'intervention de l'Assurance Qualité permet d'articuler la gestion de crise. Le service a une posture extérieure et neutre avec une vue globale de la situation. Il a la légitimité nécessaire pour organiser des confrontations de points de vues et créer des zones de négociation autour d'objets frontières comme les tableaux de résolution de problème.

5.2.4 Des mécanismes transfrontières pour favoriser les échanges entre services et légitimer les demandes de l'atelier

Cette partie présente cinq dispositifs organisationnels qui contribuent à la résilience globale :

- *L'esprit Lean* : cette philosophie peut contribuer à la résilience par la réhabilitation de l'atelier aux yeux des services supports, le développement de relations client-fournisseur internes, la participation des opérateurs à l'amélioration continue et des méthodes structurées de résolution de problème.
- *Les formations pour les services supports* : cette formation au Lean est basée sur une simulation de production grâce à des Lego®. Ce jeu permet de recréer un flux de production et de confronter les participants aux difficultés rencontrées en production. Dans ces situations, les participants doivent être résilients pour gérer les aléas ensemble.
- *Le management terrain* : un des principes clés du management terrain est de se déplacer dans l'atelier pour voir de ses propres yeux ce qu'il s'y passe. C'est vrai pour l'encadrement mais aussi pour les fonctions support. Dans cette perspective toutes les réunions concernant l'atelier, qui se tenaient dans des salles de réunion devant des tableaux Excel, ont été déplacées dans l'atelier devant des tableaux blancs.
- *Les groupes de travail interdisciplinaires* : pour encourager la coopération dans la résolution de problème qui concernent différents départements, des groupes de travail ont été mis en place sur des problèmes majeurs et/ou récurrents (problèmes de serrage, de documents d'assemblage, harmonisation technique entre deux produits, etc.).

5.2.5 Création d'objets frontière efficaces

Le concept d'objet frontière est particulièrement utile dans les situations de résolution de problème, lorsque des acteurs doivent se coordonner autour d'un objectif commun. Ces objets permettent l'articulation de la connaissance de différents acteurs, souvent de manière innovante. Dans l'entreprise étudiée, les tableaux qualité peuvent prendre en charge cette fonction.

5.2.6 Conclusion

Cette section a proposé différents dispositifs organisationnels favorisant la résilience et la transversalité dans la résolution de problème. Elle a montré les limites d'une résilience reposant uniquement sur des individus. Des mécanismes plus formels et fiables sont nécessaires. Les formations et les groupes interdisciplinaires permettent de réduire les écarts entre les services en les alignant sur un objectif commun. Des objets frontières peuvent aussi contribuer au travail d'articulation. Les résultats de la mise en œuvre de ces propositions sont exposés dans le chapitre 6.

Chapitre 6 Expérimentation et validation des propositions

Ce chapitre détaille la mise en œuvre de la méthode de contrôle de la propagation et des dispositifs organisationnels présentés au chapitre 5. Cette expérimentation a été effectuée dans l'entreprise étudiée et étendue à une autre entreprise du groupe opérant sur le secteur des volumes élevés avec forte personnalisation des produits (personnalisation de masse).

6.1 Mise en œuvre de la méthode de contrôle de la propagation

Cette mise en œuvre s'est déroulée en trois étapes : tout d'abord une analyse rétrospective sur des données historiques concernant les problèmes qualité rencontrés durant une année, suivi d'une mise en œuvre en temps réel durant trois mois et enfin une automatisation de la méthode dans la deuxième entreprise pour valider sa pertinence dans un autre contexte industriel.

6.1.1 Etude rétrospective

Les deux niveaux de la stratégie de contrôle (système et événement) présentés au chapitre 5 ont été mis en œuvre simultanément. L'analyse est basée sur 41 rapports qualité formels édités sur une période d'un an pour un produit. Les informations ont été clarifiées et complétées par des interviews des équipes qualité.

6.1.1.1 Niveau système

Le processus d'assemblage a été divisé en 15 macro-opérations. Les 41 non-conformités ont été enregistrées dans une matrice de propagation 15x15. La propagation moyenne pour ces 41 défauts est de 6 étapes dans le processus. La perméabilité moyenne des opérations est de 43%, ce qui signifie qu'une opération laisse passer en moyenne 43% des défauts qui l'atteignent.

6.1.1.2 Niveau événement

Cette analyse a permis de construire les cartes de contrôle des distances individuelles ainsi que des écarts glissants (*moving ranges*). Elle a permis de confirmer que les limites statistiques classiques (Montgomery, 2007) ne sont pas adaptées à ce type d'utilisation, même si la distribution des distances de l'échantillon vérifie l'hypothèse de normalité. Ces limites sont en effet trop élevées pour permettre la détection des déviations. D'autres définitions des limites ont donc été proposées.

6.1.2 Etude en temps réel

Les données sur les non-conformités ont été collectées sur une période de trois mois, d'avril à juillet 2011, à partir des rapports qualité. La carte de contrôle a été complétée au fur et à mesure pour chaque nouveau problème. La matrice a été alimentée avec les données des trois mois.

6.1.2.1 Niveau événement

Des actions ont été entreprises dès qu'un défaut a dépassé le seuil de propagation. Le système a donné lieu à six alarmes sur la période de trois mois. Cette mise en œuvre en temps réel a montré que la méthode est adaptée à la détection de faiblesses dans le système de protection. Les alarmes ont en effet pointé des déficits de contrôle ou des contrôles poreux. De plus la quantité d'alarmes est gérable et les alarmes non pertinentes sont rapidement éliminées par l'équipe qualité. Chaque alarme a été discutée entre l'équipe qualité et la production pour décider des actions à mettre en œuvre.

6.1.2.2 Niveau système

Durant la période de trois mois, 25 défauts ont été enregistrés dans la matrice. La distance moyenne de propagation est de 3,5 étapes dans le processus (40% de moins que dans la première étude) et la perméabilité moyenne est de 31% (soit 12% plus basse que dans la première étude). La situation s'est donc globalement améliorée entre les deux études. Cette amélioration est due à toutes les initiatives qualité entreprises par l'usine, dont celles mises en œuvre après la première étude sur la propagation.

6.1.3 Test dans une autre industrie

Après les deux études précédentes dans le secteur des faibles volumes, la méthode a été proposée à une autre entreprise dans le secteur de la personnalisation de masse. Cette entreprise fabrique des transmetteurs de pression pour des applications industrielles. Les produits sont hautement personnalisables mais fabriqués en grande série (140 000 par an). Grace à son ERP l'entreprise possède des enregistrements détaillés de ses problèmes qualité. Environ 300 défauts sont enregistrés chaque mois. L'analyse a été conduite sur une période de trois mois et a été complétée par des observations directes sur la ligne d'assemblage ainsi que par des interviews. Le processus a été décomposé en 30 étapes.

6.1.3.1 Automatisation de l'outil

Vu le nombre élevé d'enregistrements, une automatisation de l'outil est nécessaire. Grace à la définition d'un « catalogue erreurs » exhaustif et l'association de postes de génération à chaque erreur, le calcul de la distance a pu être automatisé à partir de l'ERP.

6.1.3.2 Niveau événement

L'outil permet de renvoyer de manière quotidienne ou hebdomadaire les défauts qui se sont propagés au-delà du seuil de propagation. Le seuil et la fréquence sont réglés par l'équipe qualité.

6.1.3.3 Niveau système

Ce niveau d'analyse est utilisé pour évaluer la porosité des différentes étapes du processus. L'analyse est conduite chaque mois ou chaque trimestre. La distance moyenne sur la période étudiée est de 11 étapes. L'analyse des postes les plus perméables a donné lieu à des recommandations pour l'entreprise.

6.1.4 Discussion

La méthode proposée vise à réduire la propagation des non-conformités dans le processus de réalisation. L'indicateur de propagation donne une vue macroscopique de la performance du système de protection. Tous les types de défauts sont agrégés dans cette méthode qui permet d'analyser la profondeur avec laquelle les défauts traversent les barrières de protection (distance de propagation) ainsi que la taille des brèches dans ces barrières (indicateur de perméabilité). Cette méthode est un outil d'aide à la décision qui met en évidence où les efforts d'amélioration doivent être dirigés.

Les limites de la méthode concernent tout d'abord l'indicateur de perméabilité, qui reste relatif car il prend en compte uniquement les défauts enregistrés. Les défauts qui sont rattrapés sont transparents pour le système. Une deuxième limite concerne la disponibilité des données qualité qui peuvent être compliquées à obtenir, surtout les postes de génération des défauts. Une troisième limite concerne l'indicateur de propagation calculé en nombre d'étapes dans le processus qui ne prend pas en compte les possibilités de détection à chaque étape. Enfin, cet indicateur ne prend pas en compte la position de l'étape dans le processus. Une évolution pourrait être d'introduire une pondération sur les étapes qui augmenterait au fur et à mesure que l'on se rapproche de la fin du processus.

6.2 Mise en œuvre des dispositifs organisationnels

6.2.1 Formation Lean

Les participants ont été globalement très satisfaits de la formation. Une évaluation de la compréhension des concepts a été réalisée à la fin de la formation et a été reconduite trois mois après la formation pour vérifier leur assimilation. Trois mois après la formation, 86% des personnes interrogées sont capables d'expliquer les principes clés du Lean et 75% d'entre eux voient un exemple de mise en œuvre du Lean dans leur quotidien.

Ces formations et la diffusion de la philosophie lean ont permis de contribuer significativement à l'amélioration de la résilience par :

- la réhabilitation de l'atelier, en faisant comprendre aux différents acteurs leur rôle dans l'objectif commun qui est de fournir un produit au client avec le niveau de qualité et dans les délais exigés.
- la compréhension des contraintes de production par les services supports qui ont compris les raisons de la réactivité qui leur est demandée dans leurs interventions.
- la création de réseaux d'experts internes. Les formations ont permis de faire se rencontrer les différents métiers de l'entreprise, ce qui augmente pour les participants la compréhension du fonctionnement global de l'organisation. En cas de problèmes ils savent désormais à qui s'adresser.
- la compréhension de l'articulation du processus de réalisation pour les opérateurs et les chefs d'équipe qui n'ont pas la vision globale de ce processus.
- la compréhension de la complexité des documents d'assemblage. La formation a permis de mettre en évidence que les documents d'assemblage ne sont pas conçus dans une optique client-fournisseur. Les services supports oublient souvent que le client des documents est la production.
- l'impact des non-conformités qui se propagent en terme de perturbation de flux : les non-conformités génèrent des reprises qui doivent être gérées par la ligne en parallèle de la production normale et qui perturbent le flux. Le jeu a mis en évidence les erreurs qui peuvent être commises en cas de reprises ainsi que le stress qu'elles induisent pour les opérateurs.

6.2.2 Management terrain

6.2.2.1 Evaluation des réunions terrain

Différentes réunion transverses ont été mise en place dans l'atelier (réunion qualité, réunion de lancement de production, réunion sur le planning et les manquants) pour favoriser les échanges entre les services particulièrement autour des problèmes de l'atelier. Elles ont permis de gagner :

- en réactivité grâce à des échanges institutionnalisés et réguliers (quotidiens ou hebdomadaires)
- en fiabilité : les informations sont disponibles de manière unique pour tous les acteurs sur les tableaux
- en temps de cycle : les temps de cycle des différents sous-processus comme la préfabrication ont été réduits grâce à la mise en œuvre de solutions pérennes et partagées
- en partage d'information : par exemple sur les spécificités des projets

- en transparence sur les problèmes : ils sont affichés aux yeux de tous
- vue d'ensemble : le travail des opérateurs est inscrit dans le contexte du projet grâce aux réunions de lancement de production

Pour faire face à la demande croissante de réactivité, les services supports se sont réorganisés et ont créé des équipes de réponse rapide pour dépanner la production au plus vite en cas de blocage.

6.2.2.2 Evaluation des groupes de travail interdisciplinaires

Le tableau ci-dessous récapitule les données concernant les quatre groupes de travail qui ont été animés ou co-animés par le chercheur. Des changements majeurs ont été réalisés grâce à ces groupes, par exemple la standardisation de l'unité des couples de serrage entre les documents d'assemblage. Des actions sur le long terme ont aussi émergé de ces groupes comme les semaines qualité thématiques.

	Serrage	Documents	Déménagement atelier	Harmonisation technique
Objectif	Eliminer les problèmes de serrage (30% des problèmes qualité enregistrés)	Eliminer les problèmes liés aux documents (50% des problèmes qualité enregistrés)	Analyse de risques concernant le rapprochement de deux lignes de production	Harmonisation des méthodes et des documents d'assemblage entre deux produits
Durée	Fév. 2010- Av. 2010	Oct. 2010- Jan. 2011	Déc. 2010-Sept 2011	Fév. 2011-Juil. 2011
Nombre de réunions	5	7	15	10
Participants	Opérateur, Chef d'équipe, Agent de maitrise, support industriel, support technique, qualité, formateur technique	Opérateur, Chef d'équipe, Agent de maitrise, support industriel, support technique, bureau d'étude, qualité, formateur technique	Agent de maitrise, support industriel, support technique, qualité, formateur technique	Opérateur, Chef d'équipe, Agent de maitrise, support industriel, support technique, qualité, formateur technique
Statut du chercheur	Animateur	Animateur	Co-animateur	Co-animateur
Résultats	Standardisation de l'unité du couple de serrage Réattribution des outils sur les postes de travail Flyer de communication sur les règles de serrage	Pas de simplification documentaire Standardisation des picking-list pour la préparation des kits	Formation opérateurs (2 smn) Code couleur (documents, composants, postes, etc.) pour distinguer les deux produits Harmonisation technique	modifications de plans (70) et d'instructions de montage (40 10 réunions de diffusion des nouveaux documents dans l'atelier

Plan d'actions résultant	Audits	Questionnaire sur les pratiques de managements des chefs d'équipes et agents de maitrise Semaines qualité thématiques	Présence terrain des services supports pendant 3 semaines après le déménagement	Audits, mémos sur les différences entre les produits
REX	Pas de solution technique Standardisation de l'unité de couple Propositions de solutions organisationnelles	Pas de simplification à cause de la « propriété » des documents Pas d'alignement vers les besoins du client (production)	Bonne préparation avant le déménagement, bonne collaboration entre les supports	Charge de travail importante pour les supports, aurait dû commencer plus tôt

Caractéristique des groupes interdisciplinaires

6.2.3 *Evaluation des objets frontières : les tableaux qualité*

Les tableaux qualité jouent un rôle partiel d'objets frontières. Ils sont la référence en termes d'information sur les problèmes en cours. Ils sont devenus des objets frontières car ils constituent des lieux d'échange et de coordination entre les services, où ces derniers créent ensemble une représentation commune des problèmes. Cependant, l'efficacité des échanges repose beaucoup sur l'animation des réunions par le service qualité.

6.2.4 *Discussion*

6.2.4.1 Contribution du jeu

Le jeu proposé dans la formation au lean manufacturing a permis de simuler un flux de production et de mettre les participants en situation de résolution de problème. Il a permis d'illustrer des phénomènes comme la propagation des non-conformités, dans un environnement maitrisé aux enjeux limités. Les participants ont pu créer des parallèles avec les situations qu'ils vivent au quotidien.

6.2.4.2 Travail de réarticulation

Toutes les approches présentées dans ce chapitre ont pour but de réarticuler les tâches et de donner du sens à leur positionnement les unes par rapport aux autres. Elles ont contribué à créer des interfaces matérialisées par des objets ou des individus. Nous avons rencontré les limites d'une résilience qui reposent uniquement sur des individus (chef d'équipe) ainsi que des limites dues aux compétitions entre territoires organisationnels (groupe de travail sur les documents).

6.2.4.3 Objets frontières

L’exemple des tableaux qualité questionne la dimension de l’animation autour de l’objet pour une utilisation efficace.

6.2.5 Conclusion

Cette section a présenté la mise en œuvre et l’évaluation des dispositifs organisationnels présentés au chapitre 5 pour favoriser la résilience et la transversalité dans la résolution de problème. L’efficacité de ces outils dépend cependant de la manière dont ils sont mis en œuvre.

6.3 Evaluation du projet de recherche

Comme décrit au chapitre 4.3, la fiabilité et la validité du projet de recherche doivent être évaluées sur différents aspects qui sont détaillés ci-dessous pour notre projet :

- la fiabilité : l’utilisation de protocoles de recherche permet de garantir que l’étude pourrait être répétée
- la validité des concepts : assurée par les sources multiples de données et la triangulation des données effectuée dans les différentes phases du projet
- la validité interne : pour réduire le biais lié à l’immersion du chercheur dans l’entreprise, les résultats ont été systématiquement discutés avec d’autres chercheurs extérieurs et lors de conférences internationales
- la validité externe : la généralisation des résultats a été testée dans une autre industrie

Chapitre 7 Conclusion

Ce chapitre revient sur les principaux résultats obtenus dans ce travail de thèse.

7.1 Contributions principales

7.1.1 Approche interdisciplinaire

La première contribution de ce travail de thèse concerne l'approche interdisciplinaire qui a été adoptée pour traiter le problème de la propagation des non-conformités. Ce projet de recherche transverse a combiné les disciplines de la qualité industrielle ainsi que de la fiabilité et de la résilience organisationnelle. Ces deux perspectives se sont enrichies mutuellement durant tout le projet.

7.1.2 Pertinence de l'outil de maitrise de la propagation

Les entreprises industrielles mettent en place différents mécanismes pour se protéger contre les non-conformités : d'un côté des analyses de risques pour prévenir les défauts, de l'autre des systèmes de détection pour les stopper au plus vite après leur apparition. Ces dispositifs présentent cependant des brèches qui laissent passer certains défauts, qui vont se propager et qui peuvent induire des couts élevés en termes de rebuts, reprises, délais, stress, voir d'accidents ou de rappel de produit. Ce travail de thèse s'intéresse à la mise sous contrôle de ce phénomène de propagation pour améliorer la performance globale du système de contrôle et donc la fiabilité des produits délivrés. Il propose une méthode d'aide à la décision à deux niveaux, à destination des équipes qualité pour identifier les faiblesses du système de protection. Cette méthode a été mise en œuvre dans deux entreprises du groupe Siemens.

7.1.3 Pertinence des dispositifs organisationnels proposés

7.1.3.1 Le concept de résilience dans le domaine de la qualité industrielle

La résilience est une pratique de management qui apparaît comme pertinente en dehors du domaine de la sureté de fonctionnement et des analyses d'accidents pour lesquels elle a été principalement théorisée. Elle est particulièrement adaptée au management de situations quotidiennes perturbées ou au cas des crises par « accumulation » qui touchent particulièrement les industries de faible volume. Ces entreprises sont régulièrement confrontées à des non-conformités, qui n'ont pas pu être évitées et qui se propagent, que les théories sur la résilience permettent de prendre en compte.

7.1.3.2 Les différentes formes de résilience

Cette thèse a mis en évidence trois types de résilience basés sur des rattrapages mais qui ne renvoient pas au même engagement des acteurs. Dans la deuxième entreprise étudiée, la résilience repose sur une ligne de production redondante qui inclut des postes de réparation. Les problèmes qualité sont délégués à ces postes ce qui nécessite un faible engagement des autres acteurs en matière de qualité. Dans la première entreprise étudiée la résilience repose sur le management improvisé et informel des non-conformités et sur l'engagement élevé des acteurs dans le processus de rectification. Le troisième type de résilience proposé dans cette thèse est basé sur un « réseau » de résolution de problème pris en charge par l'organisation, qui crée des zones de confrontation et de négociation et des processus supports. Comme le deuxième type de résilience, il repose sur l'engagement des acteurs mais vise à impliquer plus d'acteurs et à favoriser la coopération et la réactivité.

7.1.3.3 Le cout de la résilience

Les différentes formes de résilience présentées ci-dessus doivent être évaluées sur la base de leur efficacité à long terme et des couts humains et organisationnels associés. Les rattrapages ont un cout économique pour les entreprises en termes de composants et de main d'œuvre. A cela s'ajoute dans les deux entreprises étudiées un cout humain lié à la perte de sens du travail, à la lassitude et au désengagement des acteurs. Dans la première entreprise, la résilience repose essentiellement sur des individus qui rectifient une grande partie des non-conformités. Cette forme de résilience peut induire un phénomène de débordement des acteurs. La troisième forme de résilience présente également des limites, car elle est basée sur une organisation « parallèle », couteuse à gérer et à maintenir, particulièrement en cas de départ des acteurs.

7.2 Perspectives

Suite à ce travail de thèse, plusieurs perspectives de recherche peuvent être identifiées. Tout d'abord, concernant l'outil de maitrise de la propagation, des développements pourraient être conduits pour affiner la méthode :

- Les paramètres du modèle de propagation doivent être étudiés et ajustés. Les indicateurs de propagation et de perméabilité sont basés sur une distance calculée en nombre d'étapes dans le processus de fabrication. D'autres mesures pourraient cependant être utilisées, en particulier une mesure prenant en compte la valeur ajoutée. De plus, le modèle ne prend pas en compte le positionnement du lieu de détection dans le processus. Un développement pourrait inclure un facteur de criticité dans la mesure de la propagation pour refléter le risque croissant de propagation à l'extérieur lorsque la détection se rapproche de la fin du processus.
- Ensuite, l'outil pourrait être mis en œuvre sur une période plus longue pour pouvoir mesurer l'impact des actions et étudier le lien entre la propagation et les couts de non-conformité.

- La généralisation de la méthode à d'autres industries doit aussi être validée. Ceci pourra mettre en évidence de nouveaux enjeux et de nouvelles opportunités de développement. Le domaine des services et particulièrement celui des hôpitaux nous semble très prometteur.
- Enfin, l'outil de maitrise de la propagation pourrait être étendu en amont de la production (conception, logistique, etc.). Il deviendrait alors un instrument de mise en évidence de problèmes transfrontières au niveau de l'organisation.

En outre, des pistes de recherche dans le domaine des risques transfrontières et de la résilience ont aussi été identifiées :

- Le thème de la résilience dans le domaine de la production et particulièrement dans celui de la qualité a été très peu étudié. Pourtant nous avons identifié une opportunité d'utilisation de ce concept pour améliorer la performance industrielle. D'autres travaux de recherche sont nécessaires dans ce domaine.
- Un second axe de recherche concerne le concept de risque de « sur-vigilance » qui peut être associé à la résilience. Beaucoup de travaux sur la résilience ont présenté les aspects positifs de cette pratique. Ce travail de thèse a permis de nuancer ces résultats et a présenté des limites de la résilience concernant le potentiel débordement des acteurs impliqués dans ces mécanismes. D'autres travaux permettraient d'approfondir l'analyse de la relation entre résilience et débordement des acteurs, particulièrement dans le cas des crises par « accumulation ».
- Enfin, cette thèse illustre des problèmes liés aux documents. Comme l'explique (Tillement, 2011), les documents sont souvent au cœur des problématiques sur les risques. Les documents renvoient à des questions de métiers. Ils circulent entre les métiers et sont censés jouer un rôle de coordination. Cependant, ils échouent fréquemment dans cette fonction d'objet frontière et peuvent même induire en erreur. Il serait intéressant d'étudier dans une approche interdisciplinaire ce qui rend ces objets inopérants et comment ils pourraient être transformés en véritables objets frontières.

CHAPTER 1 INTRODUCTION

1.1 Research background

Industrial performance has been a major concern for companies since the beginning of the industrial era. Its evaluation has however evolved from a single productivity indicator to a global and multi-criteria evaluation policy. The considered dimensions include volumes and the classical time-cost-quality triangle but also indicators for flexibility, safety, social performances, environmental performance, and reliability.
The evolution toward socio-economical consideration as well as the increasing complexity of industrial systems implies a need for interdisciplinary research. More generally, in recent years there has been a growing consensus in the Operation Management (OM) field about the benefits of drawing insight from major theories in other fields such as economics, management and organization theory (Buhman et al., 2005; Handfield, 2006; Sousa and Voss, 2008). Theories in system engineering also recommend thinking in terms of a total system, rather than just a specific discipline (Haskins, 2006). Especially the risk management field requires an interdisciplinary approach for better understanding and management of industrial risks (Magne and Vasseur, 2006). Industrial risks are defined by (Magne and Vasseur, 2006) as risks that have to be considered by organizations that build, run, and control industrial facilities. This notion of industrial risks encompasses both risks linked to failures and economical risks.

Among the industrial risks, this work focuses on the risk of non-conformities in product delivery reaching the customer. The recent case of Toyota (Montgomery, 2010) and its massive recall illustrates the losses in terms of costs and reputation induced by such events, and questions the ability of firms to master their industrial processes. Even leading companies that put great effort into quality and continuous improvement experienced such hazard (see the examples of Mercedes (Reuters, 2011), Airbus (The Guardian, 2012)). A product recall materializes the worst non-conformity propagation case, in which a defect has reached a final customer. It questions the performance of the protection system of industrial companies, i.e. the various mechanisms set up by firms to protect against non-conformities: on the one hand, risk analysis to prevent defects, and on the other hand, detection systems in order to detect them as soon as they occur. This quality issue is even more crucial in low volume productions in which no one can afford a product breakdown at the customer's level nor wait until a failure replicates itself before acting.

The question of the reliability of a production system has been widely addressed in the quality control literature. But the performance of global protection system has been less studied especially in low volume industries. The quality performance is measured in terms of scrap, yield or detection quality and speed. But how can this performance be managed when statistical analysis is not possible because of a lack of data?

A relevant concept relating to the propagation found in the safety field literature is the use of protection barriers or protection layers especially as applied to technical systems in the process and nuclear industries(Magne and Vasseur, 2006). Layers of protection (Summers, 2003; Sklet, 2006; Hollnagel, 2008; Duijm, 2009) illustrate the efforts to prevent propagation of failures and to stop them as close as possible to their origin in order to limit their impact at least in terms of costs by allowing rework as soon as possible and avoiding "late" rework. From this perspective, safety relies on successive defence lines or barriers, which protect the organization against dangers. In the industrial quality field, these protection layers are, for example, control charts, preventive maintenances, acceptation tests, and inspections. These measures can however present weaknesses, materialized by holes and let some defects slip through and propagate, sometimes up to the final customer in the case of aligned holes as illustrated in Figure 1-1.

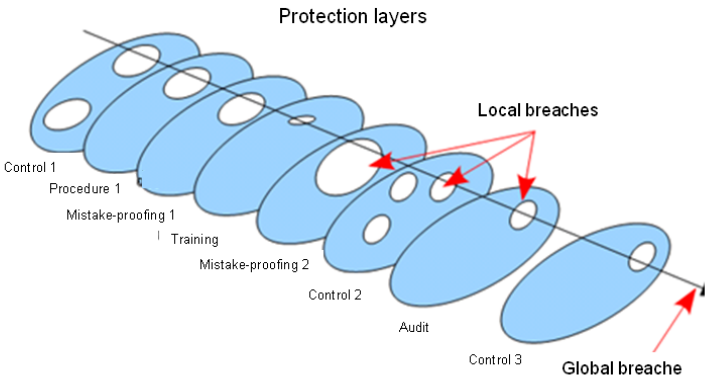


Figure 1-1: Protection layers and breaches

Although prevention in many ways is better than protection, it is a fact of life that perfect prevention is impossible. This realisation has been made famous by the observation that there is always something that can go wrong (Hollnagel, 2008).

In this perspective, recent approaches of risks and organisational resilience present irregular variations and degradation of expected working conditions as a component of the daily life of organizations. This theoretical change is partly due to the works about the organizational resilience (Weick, 2001; Hollnagel et al., 2006; Barton and Sutcliffe, 2009). It can be seen as a reversal of the classical perspectives about the control of risks because it means that reliability is not the absence of unforeseen events and variations, but the ability for an organization to take in charge "the irregular variations, disruptions and degradation of expected working conditions" (Hollnagel et al., 2006) and to cope with unanticipated dangers and uncertainties (Douglas and Wildavsky, 1983).

Therefore, we choose to characterise the performance of the protection system of an industrial company by the absence of non-conformities reaching the end customer, and by extension the absence of non-conformities passed to internal customer, i.e. the speed of non-conformity detection.

The concept of permeability has to be adapted to the case of low volume productions in which it cannot be afford to wait until a failure impacts several products to adjust detection. In the aeronautic field for example, it is easy to understand that no one can wait until several airplanes are impacted by a potentially harmful defect before acting. This research thus focuses on the multi-disciplinary issue of quality and reliability of production systems in low-volume manufacturing from the perspective of the performance of protection systems and adopts a transversal approach coupling the engineering field of quality control performance and the organizational dimension of reliability and resilience. Moreover, this work aims at addressing this question from an applied research approach. It consists in coupling two perspectives: on the one hand the practical problems of industrial actors, and on the other hand research questions that will enable knowledge building in the long-term.

1.2 Industrial background

The research presented here was conducted with an industrial partner on the basis of a CIFRE (Convention Industrielle de Formation par la Recherche en Entreprise) agreement. This funding of the French government aims at fostering research partnerships between companies and public laboratories.

The industrial partner involved in this project is Siemens ETHS in Grenoble, branch of Siemens AG, a global powerhouse in electronics and electrical engineering. Today, Siemens is active in around 190 regions, occupying leading market and technology positions worldwide with its business activities in the Energy, Healthcare, Industry, and Infrastructure & Cities Sectors. Overall, with 360,000 employees around the world, Siemens is well positioned to offer its customers local, targeted, and tailored solutions.

In fiscal year 2011, Siemens had global revenue of €77,7 billion.

Energy

Divisions
- Fossil Power Generation
- Wind Power
- Solar & Hydro
- Oil & Gas
- Energy Service
- Power Transmission

High-voltage Substation

Healthcare

Divisions
- Imaging & Therapy Systems
- Clinical Products
- Diagnostics
- Customer Solutions

Industry

Divisions
- Industry Automation
- Drive Technologies
- Customer Services

Infrastructure & Cities

Divisions
- Rail Systems
- Mobility and Logistics
- Low and Medium Voltage
- Smart Grid
- Building Technologies
- OSRAM*

Figure 1-2: Sectors and divisions of Siemens AG, as of October 1, 2011

Siemens Energy Sector is one of the world's leading suppliers of a wide range of products, solutions and services in the field of energy technology. The manufacturing factory in Grenoble ETHS (Energy Power Transmission High-Voltage Substation) develops and manufactures gas-insulated switchgears for high-voltage substations, which are electrical nods of the power network for power transmission and distribution.

The customers of Siemens ETHS are mainly national or private electricity companies like RTE in France, Hydro Quebec in Canada or RWE in Germany. The plant works to order, manufacturing customised equipment meeting the needs of each customer. This means great variation in design and assembly.

The company belongs to the particular field of low-volumes industries like aeronautics, dam industry, and plant installation. Low-volume industries cover a wide range of companies associated with capital goods (e.g. offshore structures, power generation plant, etc.) and intermediate product markets (e.g. pumps, valves, etc.) and supply a wide range of industries (e.g. power generation and distribution, oil exploration, etc.) (Maffin and Braiden, 2001). Very few works have been retrieved concerning the low volume context. (Maffin and Braiden, 2001; Surbier, 2010) investigate these types of industries regarding issues of New Product Development and ramp-up. (Heike et al., 2001) investigate alternatives for mixed model assembly in low-volume manufacturing environment. (Jina et al., 1997) examine how lean principles can be applied for high product variety and low volumes.

According to these works and our field studies, low volume industries have the following characteristics:

- Their products tend to be manufactured for downstream industrial producers and to be used in the production of other goods and services, rather than for final household markets
- They often operate in a make-to order market. This means a high level of customization and thus a high level of product diversity. In some cases, products can even be developed to a customer's particular requirement (engineer-to order)
- Due to the "make-to-order" policy with guarantees delivery dates and lead times, these companies consider time as the main production driver. They face huge penalties in case of delays.
- These industries often require a high amount of labor to produce their goods or services (labor-intensive assembly). Moreover, flexibility constraints of production lines require high-skilled workforce.
- High value added products handled by workers

Two more features can be added concerning Siemens ETHS

- 100% test and inspection of final products due to customer requirements and safety standards
- High traceability requirements (components, assembly operations, tests) coming from the norms due to high safety risks.

These characteristics can also be observed in the aerospace, aeronautic or nuclear industries for example.

Nevertheless (Jina et al., 1997) believe that organizations of the low-volume industry are facing more industrial turbulences than any other typical organization. They argue that methods and tools cannot be applied and used "as is" in this specific context. The low volume context requires the adaptation of existing results or tools from other industries or the creation of new knowledge that is adapted.

Especially in the quality field, tools, methods and organizations have to be adapted in order to face these turbulences and disruptions. Non-conformities reaching the end customer can have dramatic consequences in this type of industry. But it seems that classical quality tools are not so well suited to face the challenges of the low-volume, high variability context. Research works are really needed to understand the specificities of this type of production to select or develop relevant tools and methods.

To the best of our knowledge this specific context has not yet been addressed in studies concerning industrial performance, manufacturing quality or reliability.

In order to address this research gap, a number of research questions must be addressed. These are based on the industrial situation outlined above as well as on the literature in the field of quality and organizational resilience and will be detailed in Chapter 2.

The central research question in this thesis is the following: *How can the performance of the protection system and the resilience of a low-volume industry be characterized, measured and improved?*

1.3 Thesis outline

The dissertation presented here is structured as follows. Chapter 2 presents the formulation of the research questions showing how it has emerged jointly from the academic and the industrial partners. Chapter 3 positions our work in the literature concerning manufacturing quality and organizational resilience and reliability. It shows the emergence of an integrated approach of quality and its contingency to the organizational context. It gives particular insight into quality development in low-volume industries. It also examines the literature on transboundary risk management to highlight the relevance, but also the limits of boundary spanning activities in the management of incident and crisis. Chapter 4 details our research methodology and the different project steps. Then chapter 5 presents our proposal for the improvement of the protection system of industrial companies. This proposal is composed of quality tools and organizational design measures to work across organizational boundaries. Chapter 6 presents the implementation of our proposals in two companies of the Siemens group. Finally, chapter 7 gives our concluding remarks and perspectives for future work.

CHAPTER 2 FORMULATION OF THE RESEARCH QUESTIONS

2.1 Research motivation

The motivation for this work has emerged conjointly from the industrial partner and from the research laboratory.

The company was regularly confronted with quality problems stemming both from assembly mistakes and also during upstream stages in the process, like design, logistics, technical and industrial support. These problems would sometimes reach the end customer inducing huge losses for the company in term of costs and reputation. There was an internal feeling that these problems could come from: i) an unadapted quality system or ii) from the barriers between the organizational entities preventing efficient and sustainable problem solving.

From the company perspective there was an opportunity for transversal analysis of the failure causes.

From a research perspective there was an opportunity to study in a true multidisciplinary approach, the performance of the quality system in a low-volume and high-variability industrial context. Actually few studies were retrieved on quality problems encountered by industrial companies. As mentioned by (Garvin, 1986) few companies keep comprehensive records of their quality problems or bother to assess their organization's commitment to quality. Although such data might be collected through surveys, the possibility of bias remains. For example, the responses of workers and managers to questions about the causes of their quality problems are likely to reflect some degree of self-interest. The operational immersion of the researcher in the company is an opportunity to reduce this bias and should give good insight into the causes of quality problems and their management.

As a result, a common PhD research project was started. The project team was composed of both researchers of GSCOP (2) and PACTE (1) laboratories and from practitioners of Siemens ETHS (4). The team was interdisciplinary on both sides because it included researchers on industrial performance, process control and organization studies, and practitioners in the quality field and in continuous improvement as well as the plant manager. The project team met every three months for a steering committee, during which all decisions on the direction of further research were made. Research questions were thus defined and refined conjointly during these meetings as recommended by (Avenier, 2009). The aim of this process is to gain actionable knowledge valuable for practitioners and for researchers.

2.2 Diagnostic

The first step in the research project was a diagnostic phase during which the researcher became familiar with the organization of the company and with the manufacturing process.

We should first of all note that the manufactured equipment in the studied plant is extremely complex (several hundreds of parts) and sensitive, which entails numerous constraints for assembly operators. The littlest speck of dust can, for example, damage the product. An assembly error can have serious implications in terms of safety for employees in the factory and also for the final customer.

The studied company works in project mode. It develops and produces customized pieces of equipment at the customer's request, which requires specific design before manufacturing can begin. This process is described in the diagram Figure 2-1.

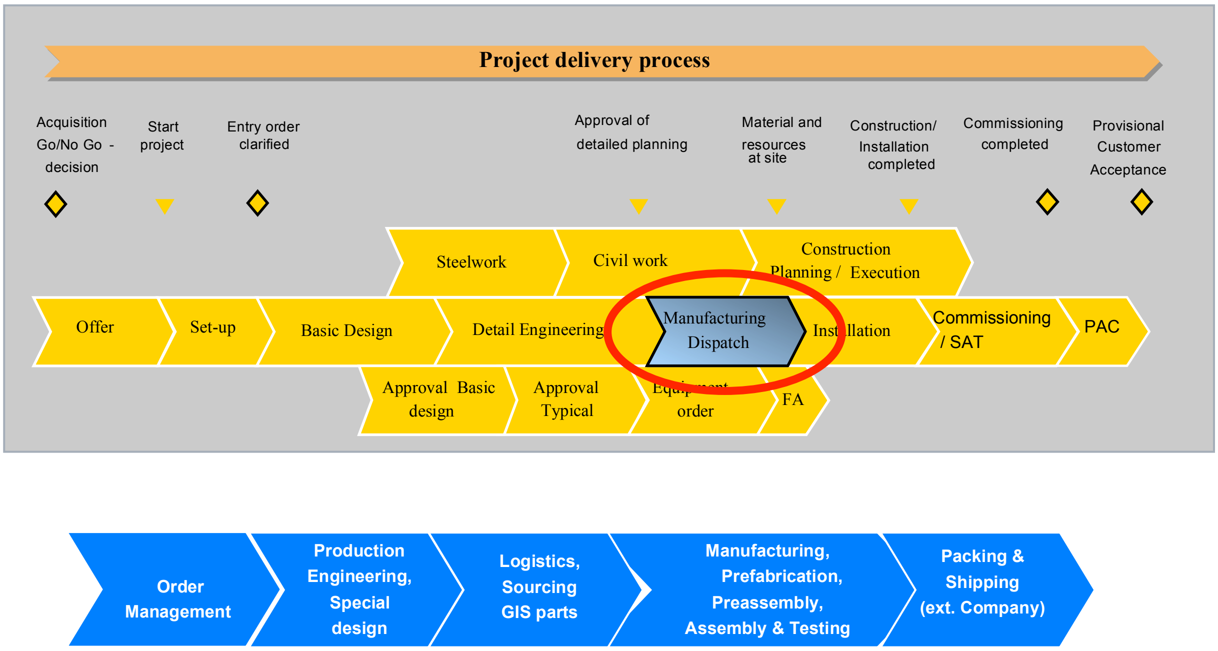


Figure 2-1: Project delivery process

The different steps in the process correspond to different teams, located at the same production site. A project manager for each order, follows the project from the offer to the on site installation and is the official customer interlocutor. He is also in charge of the coordination between the different teams but this coordination is essentially done via PLM software (for customer specification) and documents (offer, minutes of meetings, drawings, etc.). The project manager is thus more focused on external coordination. Teams have their own objectives and are not aware of the global process. They hand over their deliverables to their internal customer per email often without face-to-face interaction. This often leads to misunderstandings, or specifications that are not taken into account because they are neither highlighted nor explained.

The complexity of the product and the high level of customization for each customer bring new uncertainties for each activity phase of the process in each project. Actually, customer requirements induce design specificities for each project. These specificities lead to specific assembly drawings, meaning little standard assembly procedures and little routine for the operators. Customer requirements can also concern component quality, for example the use of specific screws, which can easily be confused.

2.2.1 Existing quality system

The factory is divided into two production lines, and a prefabrication line. The quality organization in the factory relies on different entities, for a total of 25 quality experts. The responsibilities of the different entities are detailed bellow.

- *Supplier quality*: qualification of new suppliers, or new components (2 persons)
- *Incoming inspection*: sampling inspections of incoming goods (4 persons)
- *In-line quality*: The factory is divided into two production lines, which assemble their own product. Each line has its own quality team, which is responsible for final product control and validation before shipment (quality supervisors 11 persons)
- *Quality insurance*: centralized manufacturing quality responsible for employee training, respect of the assembly procedures and problem resolution for both lines and also for the preassembly phase (washing, painting, and part preparation). (4 persons)
- *System quality*: responsible for the management system and for the certifications. (2 persons)
- *Product Quality*: design of the product control plan and associated traceability sheets (1 person)
- *Project Quality*: revision of the control plan regarding customer specifications, issuing of test reports for customers, management of the Factory Acceptance Tests (FAT) (1 person)

The positioning of these entities is demonstrated in the organization chart in Figure 2-2. The first observation is that the quality function is partitioned between different departments which puts into question its global coherence and the need for such a large number of quality experts in the company.

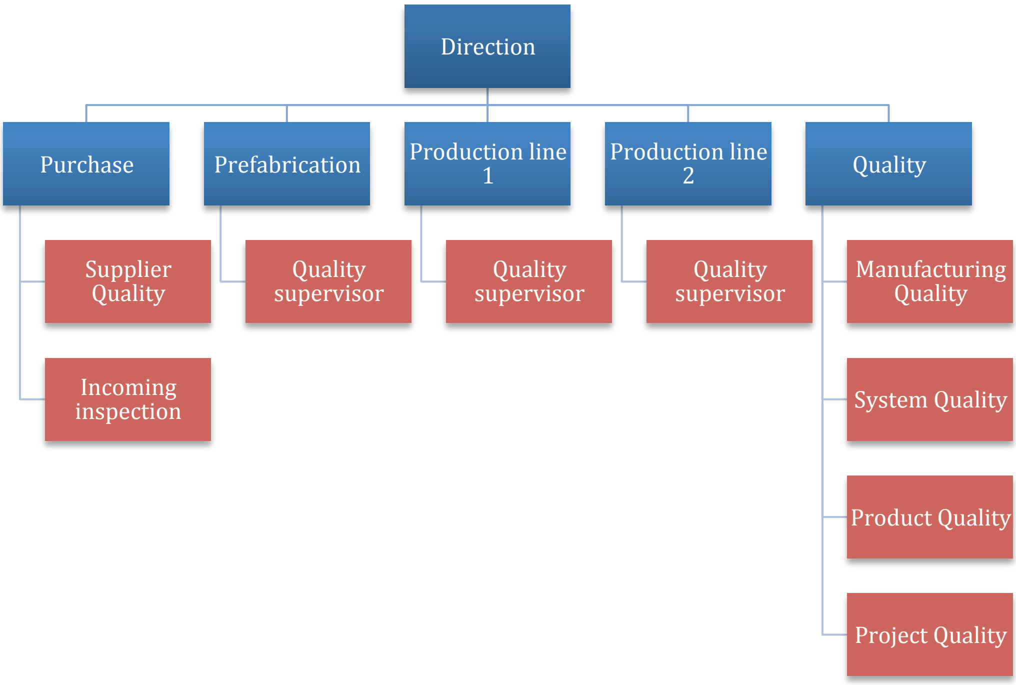


Figure 2-2: Quality teams across the factory departments

The process in place to handle non-conformities is given in Appendix VI. It distinguishes non-conformities related to the material, coming from external suppliers, and non-conformities generated internally.

The incoming inspection is responsible for the management of non-conformities coming from the supplier. These non-conformities can be detected either during the incoming inspection or during the assembly. In both cases, the incoming inspection is responsible for the claim to the supplier. It is also in charge of sorting the parts already in stock.

Other non-conformities are classified in two categories: minor or major. A major non-conformity presents risks for the customer, or of production stoppage or is a recurrence. All other non-conformities are defined as minor. Minor non-conformities are presented to the support departments during a weekly quality meeting where corrective actions are discussed. Major non-conformities are taken in charge by the quality supervisors of the line who create a non-conformity report in the shared IT tool (see Appendix VII for an example of quality report). The quality report is sent to the concerned departments for correction.

In October 2009 the plant also began a global lean transformation. Quality is one of the major objectives in the project. It aims at fostering quality culture and at standardizing the use of quality tools, particularly a structured problem solving methodology.

2.2.2 The different types of quality problems

The operational immersion and the analysis of quality reports show that the company is regularly confronted with disruptions that alter the process flow. We can say that the company has a “normally disturbed activity”; disruptions are actually part of the company’s daily proceeding. A total of 616 quality-reports have been issued in 2009 for both production lines. Quality-reports are issued for major non-conformities. The repartition between the two lines and before or after delivery is given in Table 2-1. More than 75% of these quality reports are issued after shipment, principally during on-site installation. Among these 75%, only 3% concern problems generated during on-site installation. This illustrates the propagation issue faced by the company.

FY 2009	Line 1	Line 2
Quantities produced	317	113
Quality reports before shipment	101	50
Quality reports after shipment	282	183

Table 2-1: Non-conformities in distribution

We thus choose to describe these kinds of problems as transboundary. The term “transboundary risks” is chosen first of all because of the diversity of venues where deviations occur which ultimately contribute to product failure. Each process (offer, design, logistics, manufacturing, installation) is a potential non-conformity generator. This phenomenon is amplified by the singularity of customer specificities for each project. For example, errors can occur in the offer and be detected during the specific design phase. Design errors can also occur and be detected during the manufacturing phase.

Transboundary risks also refer to the possible propagation of failures throughout the process. These defects may actually propagate beyond the borders of the stages because they are not systematically controlled nor detected. There are control checkpoints but they seem to be somewhat porous. Errors are detected when they hinder a department’s activities. Thus it is during the assembly phase that many errors are identified.

A classification of the root causes for quality problems is given in Figure 2-3. Three main root causes emerge from this analysis. The first is assembly (37%), the second is design (30%) and the third is the supplier (17%). These figures signal a need to take closer look at the assembly problems. Of the 37% bundled under the label “assembly”, a cause analysis displayed in Figure 2-4 shows that half of them may be due to incomplete or unclear information, in particular in assembly documents.

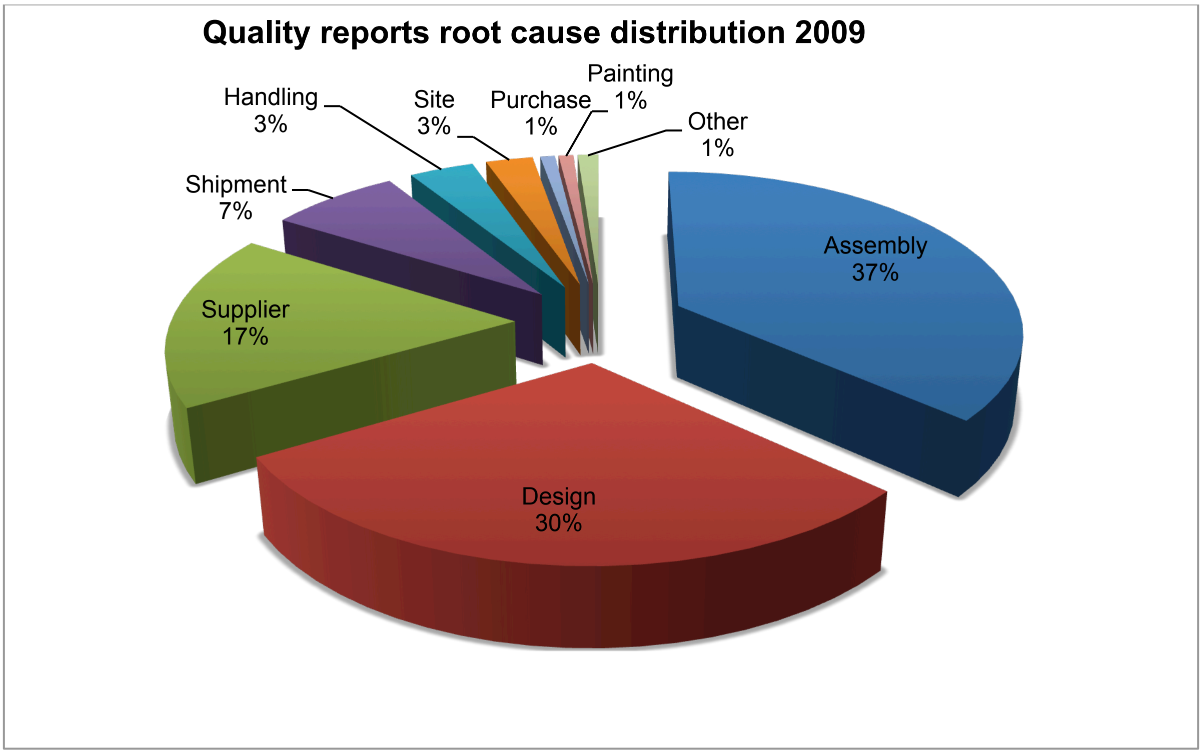


Figure 2-3: Quality problem classification

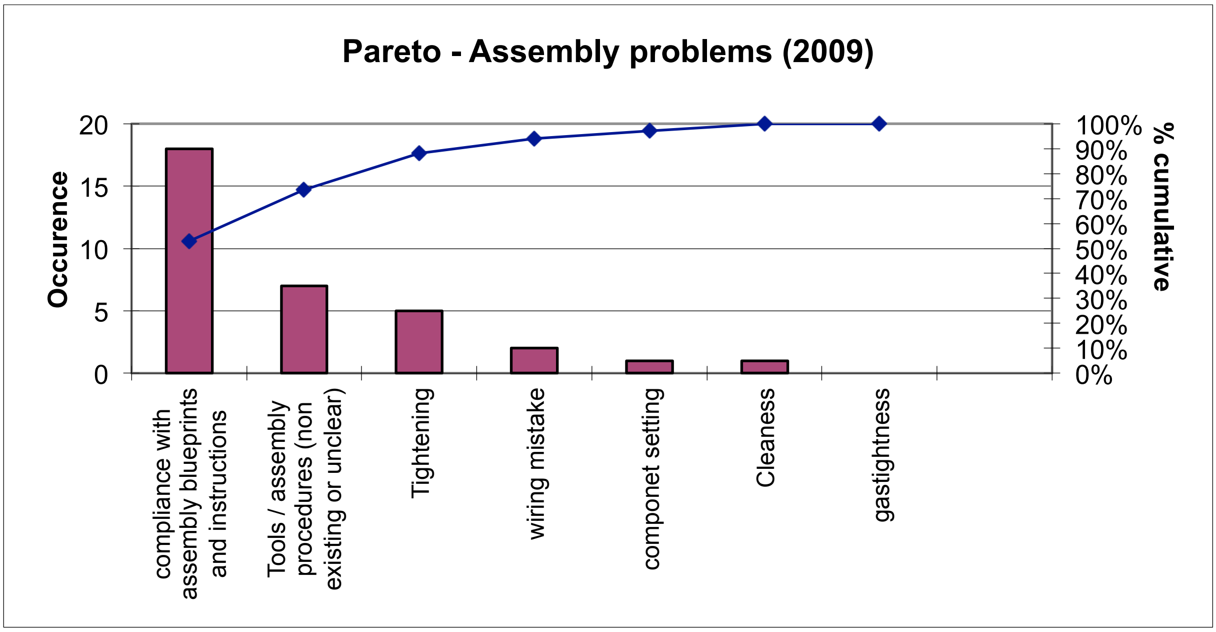


Figure 2-4: Assembly problem classification

2.2.3 Origin of the quality problems

The analysis of formal quality reports with the “Five Why” methodology, as well as direct observation and participation in quality meetings highlight different recurring root causes for the assembly problems detailed in the pareto chart in Figure 2-4:

- First of all weaknesses at the organizational boundaries: barriers exist between the different departments, particularly between the shop floor and the support departments (design, logistics, quality, methods). This is particularly noticeable during the quality meetings in which participants have difficulty accepting the requests of other departments. For example, when a request of modification of a drawing to include indication for the painting department was ask to the technical support, its response was: *"This modification is a tedious work and given the decrease in personal in our department, we won't do it"*. This modification was however necessary to ensure the final quality of the product.
- Information flow is not always effective and can cause quality problems, as well as lack of reactivity in the resolution process. More specifically when information on the encountered problem is not transmitted directly to the quality and technical support teams, who in turn often discover problems very late in the production process.
- Weaknesses in the assembly documents in terms of data updates, understanding by the shop floor, and coherency of documents issued by different departments. This is visible directly at the working stations where the quality team constantly finds obsolete documents.
- Training weaknesses: assembly mistakes can be due to a lack of training. This has been a big issue just before the beginning of this work because lots of temporary workers had been hired to face a fast increase in the production volumes. Huge quality problems arise partly due to the lack of training of people. At that time there were no specific structure dedicated to training. In response to these events a dedicated training structure has been put in place.
- Lack of vigilance: assembly operations are complex and long (between 1 hour and 7 hours). A high level of vigilance is thus required at each stage. But stress and fatigue can reduce this vigilance and induce mistakes or non-detections.
- Informal rectifications by the operator-team leader pairing can occur. This corresponds to a local problem solving. The team leader does not have a global overview of the project and may sometimes underestimate the potential impacts of the problem on the organization, as well as the consequences of his isolated corrective action, which can even reveal counterproductive.

This analysis has been shared with the quality team and presented at the steering committee in December 2009 (Fiegenwald, 2009). It has been a basis for the definition of the research questions presented in section 2.3.

2.2.4 Management of the quality problems

Like in every organization rectifications occur and avoid accident and crisis. When analyzing the management of failures and disruptions we observe two steps in the solving process: local and transboundary.

The local solving of problems is undertaken by the operator/team leader pairing. This occurs upstream from the standard process for dealing with non-conformities and is an exercise to qualify the problem to determine whether it can be rectified or not, i.e. whether they are going to be able to manage it on their own.

The second step in the solution process is a transboundary management of the incident. The team leader will then manage the problem by contacting other actors, but not necessarily the quality team, although a fault detected by an assembly operator is supposed to be passed on to quality via the team leader.

The team leader has different action possibilities, which result in different types of interventions. Table 2-2 shows the action range of the team leader who will for example do informal searches for missing information especially concerning misunderstanding or questions of document clarity. In this case he will directly address to the technical support, design teams or industrial teams. Another intervention is the pressure on upstream departments to rectify the failure. For example in the case of missing parts, he will urge the prefabrication line to solve the problem as quickly as possible.

Actually, the team leader will attempt to reduce the number of incidents that have to be reported to the Quality department.

Intervention types	Examples
Search for missing information in other departments (design team, technical service, etc.)	Drawings misunderstanding
Information interpretation	Information translation for the team, informal drawing or nomenclature correction
Pressure on upstream departments	Pressure on the prefabrication line in case of missing parts
Replacement of an actor	Parts self-service in case of unavailability of the delivery person
Request to an upstream department	Anticipation request to the upstream assembly team

Table 2-2: Interventions of the team leader

In spite of all the filters put in place by the organization and the permanent involvement of team leaders, certain problems are not rectified.

Consequences for the company can be serious with regards to costs, lead times and corporate image. An incident that has not been rectified can correspond to an incident that stops production, an incident detected during on site installation or material in use, or to a personal accident. Details on these incidents are given below.

i. These incidents are not much different from those that are rectified

Of course some non-conformities could not have been rectified, because they are undetectable before on site installation. A conception error in the global station architecture for example will only be a hindrance to on site assembly. But when looking at them, most are no different from those that are rectified (constituent defects, documentary defects, assembly errors, unavailable or unsuitable tools), the only difference being that they have not been detected. Indeed, it has been observed that detection of non-conformities is often a “chance” discovery, i.e. outside the framework of formalized controls. The company is therefore relying on the vigilance of actors.

ii. These incidents can be due to rectifications

Furthermore, informal corrections are local and occasional adjustments which do not guarantee fundamental resolution of the problem and may even lead to undesirable consequences or deviations in practices because of the application of a new method with local but not transversally effective solutions. This can occur for example when a team leader requests an isolated technical derogation on a constituent or method. The technical services involved may accept the derogation for the particular case. Generalizing this principle may not be suited for other cases, and applying it could lead to a series of other incidents.

iii. Incidents can lead to a disaster when propagating to the customer

A crisis will emerge through an accumulation of these incidents, which propagate along the process: the long period between the generation of a defect and its detection may mean that several products have been assembled and therefore potentially impacted. The response of the company is then to send experts on site to repair the defective material, analyze the root causes and the origin of the failure to identify potential risks for materials assembled in the meantime between generation and detection, in order to finally verify the conformity of the material in question.

When the research project was solicited, the company was facing a series of serious quality incidents. Its situation was more than ‘normally disrupted’ and could be qualified as an industrial crisis resulting from the accumulation of failures. These incidents have generated a feeling of uncertainty internally with respect to control and the reliability of the production process.

2.3 Research questions

Based on our first observation of the management of quality problems, we identified that these problems often persist through successive process steps before being detected, sometimes even reaching the end-customer. This observation questions the performance of the detection mechanisms in place.

We propose to study two different dimensions of the performance of the protection system of a low-volume industry. First, from a quality control perspective, we proposed to study the performance of the protection system (all the mechanisms put in place by firms to protect themselves against the consequences of non-conformities). This perspective is adopted here because, particularly in low-volume manufacturing, prevention is limited, and standard quality tools are not well adapted. Our first research question can then be formulated as follows:

RQ 1: How can the performance of the protection system of a low-volume industry be characterized?

This research question has three sub-questions:
RQ1.1: Which are the particularities of quality management in this context?
RQ1.2: Which tools and methods are relevant?
RQ1.3: Are these tools and method applicable in other industries?

As stated by (Jina et al., 1997), companies in low-volume manufacturing are facing much more turbulence than other industries. This statement has been verified empirically in the company under study, where perturbations are components of the daily activity.
Thanks to the literature and our exploratory study, we identified that in this normally disturbed environment, boundary-spanning activities and organizational resilience are necessary to ensure work continuity and to prevent non-conformity propagation. We found that resilience often relies on individuals who manage disruptions on their own what induces an illusion of reliability. This questions the limit of this form of resilience, particularly in a situation of crisis by accumulation of “normal disruptions”.
Consequently the second research question addressed in this work is the following:

RQ 2: What kind of organizational dispositions foster resilience and transversality in problem-solving situation?

It can be divided into two sub-questions:
RQ2.1: By which measure can boundary spanners and boundary objects be pillars of the organizational resilience?
RQ2.2: What methods and tools foster communication and collaboration between departments concerning quality issues and problem solving?

CHAPTER 3 LITERATURE REVIEW

3.1 Introduction: Management of quality problems - a need for early detection

Both media and research reports show that product recalls are on a rise (Berman, 1999), (Hora et al., 2011). The recent case of Toyota and its massive recall illustrates the losses in terms of cost and reputation induced by non-conformities reaching end customers but they also question the ability of the firm to master its industrial processes (Montgomery, 2010). A recall is actually due to non-conformities that have reached the end customers, meaning that they have run through all the defensive mechanisms put in place by the firm to prevent such dramatic outcomes, and illustrates the worst propagation case.

According to (Garvin, 1986), quality problems might arise from a number of sources, including poor designs or methods, defective materials, shoddy workmanship, and poorly maintained equipment.

Firms, regulators, investors and consumers are gradually recognizing that products recalls are unavoidable parts of conducting business (Berman, 1999). Even leading companies that put great effort on quality and continuous improvement experienced such hazard. As described in (Jacobs, 1996), a product recall is a vendor’s nightmare from both a financial and an organisational viewpoint. Literature on product recall is mainly directed toward efficient management of recall (reverse logistics, refund policies, insurance, etc.) (Hora et al., 2011) but gives little insight on how to avoid these dramatic events. Investigating this issue may consist in having a closer look at the propagation mechanism. (Bettayeb et al., 2010) propose an inspection allocation model for decreasing uncertainties on products. This work proposes a quality control plan that insures not to release an amount of non-controlled products above a predefined level. Their work helps in reducing uncertain products delivered to the market. They contribute to the topic of production recall prevention by actions on quality. However their developments are focused on large-scale productions. These works offer thus a research avenue for low volume productions as presented in this dissertation.

A relevant concept relating to the propagation found in the safety field literature is the use of the barrier concept within industrial safety, especially as applied to technical systems in the process and nuclear industries (Magne and Vasseur, 2006; Sklet, 2006). The best way to ensure a state of safety is either to prevent any occurrence of unexpected event or to protect against its consequences. The two primary types of responses, prevention and protection, both involve the use of barriers in one way or another (Hollnagel, 2008). Safety barriers are physical or non-physical means planned to prevent, control, or mitigate undesired events or accidents (Sklet, 2006). Layers of protection illustrate the efforts to prevent failures propagation and to stop them as close as possible from their origin in order to limit their impact. These works are inspired from the work by (Reason, 1990) and his "cheese model". This approach couples an engineering and an organisational model. In this perspective safety relies on successive defence lines or barriers, which protect the organization against dangers. An accident occurs if human or material failures make barriers ineffective. These "active failures" create holes in the different barriers. Other holes may be due to "latent conditions", i.e. errors made prior to the initiating event that triggered the accident, but whose consequences only appear during the accident. Aligned holes let the danger pass through.

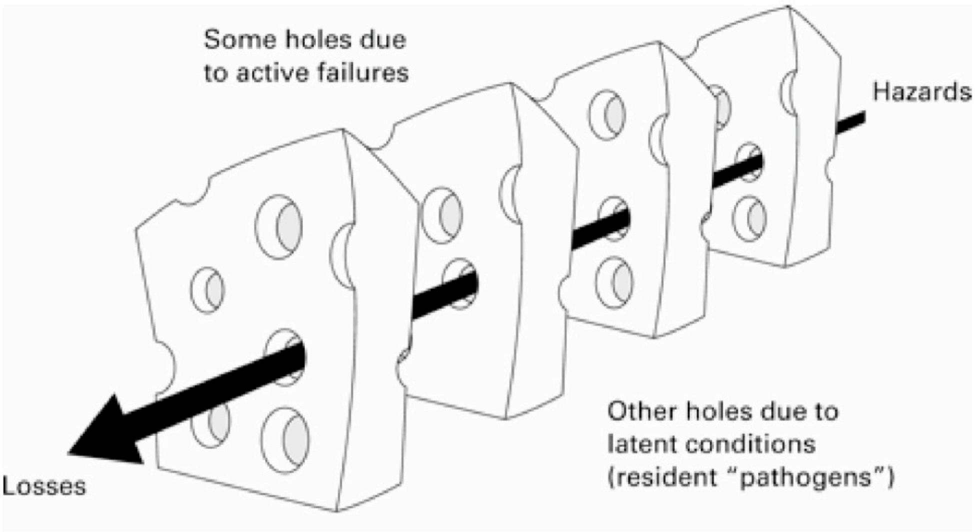


Figure 3-1: Successive layers of defences, barriers and safeguards (Magne and Vasseur, 2006)

Layers of protection (Summers, 2003; Gowland, 2006; Salvi and Debray, 2006; Sklet, 2006; Hollnagel, 2008; Duijm, 2009) illustrate the efforts to prevent failures' propagation and to stop them as close as possible from their origin in order to limit their impact at least in terms of costs. In the industrial quality field, these protection layers are, for example, control charts, preventive maintenances, acceptation tests, and inspections. The quality performance is measured in terms of scrap, yield or detection quality (sensitivity to detect drifts and the average run length before detection). But how can this performance be managed when statistics are not capable of being generated because of a lack of data?

Although prevention in many ways is better than protection, it is a fact of life that perfect prevention is impossible. This realisation has been made famous by the observation that there always is something that can go wrong (Hollnagel, 2008).
A more sophisticated version of this is (Perrow, 1994) thesis that systems by the 1980s had become so complex that accidents should be considered normal events.

According to a common safety model, safety can be brought about either by eliminating hazards, by preventing initiating events, and/or by protecting against outcomes. The best way to ensure a state of safety is either to prevent something unwanted from happening or to protect against its consequences, as illustrated by Figure 3-2. Since, in practice, it is impossible to completely prevent unwanted events, i.e., to completely eliminate risks, the two approaches are best used together.

In order to ensure safety by preventing something from happening, i.e., through the elimination of risks, it is necessary that the risks are known or can be made known. To do so is the purpose of risk assessment, and there are a considerable number of well-established methods available for that (Leveson, 1995; Tixier et al., 2002; Aven, 2003). The pursuit of safety through the elimination of risks also required that the specific risk source can actually be removed from the system without impeding or changing the system's functioning. In some cases, this condition is obviously violated when the elimination of a risk means the loss of a primary function. Thus, the risk of an airplane falling down can only be fully eliminated by not taking to the air, but that is clearly not a viable option, at least in commercial aviation.
The second option is to protect against the consequences of the critical event if or when it happens, all precautions notwithstanding. This can be done by reducing or weakening the consequences or by changing their direction either in a real or in a metaphorical sense. Note that, whereas, the first option, prevention, tries to maintain the functioning of the system and to keep it going, the second option, protection; does not need to do that. Indeed, protection may require that the system is shut down when the critical event occurs, as in the case of nuclear power plants, or that the normal functioning is reduced until the situation again has returned to normal.

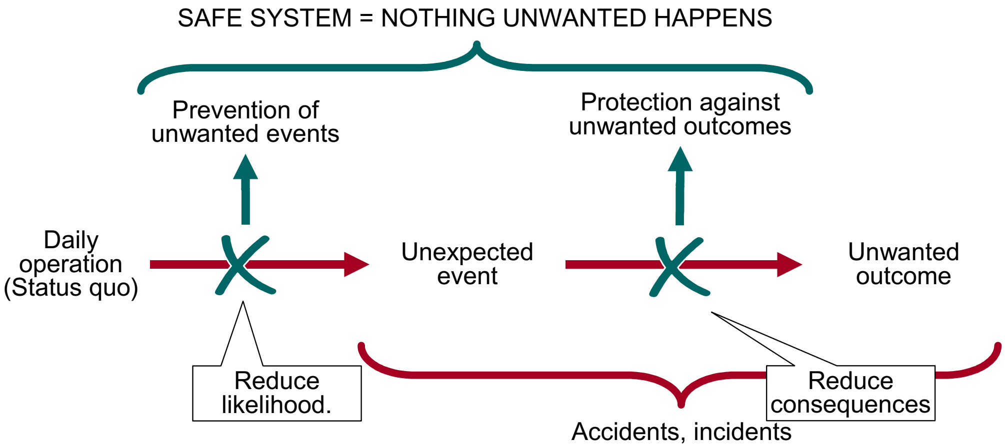


Figure 3-2: Safety through prevention and protection (Hollnagel 2008)

This research has been inspired by these publications and extends the concept of safety at all type of deviations that can affect quality in a manufacturing context. The literature has been reviewed in order to find tools and methods, which could contribute to early detection of failures in the context of low volume industries. The question of non-conformity propagation is addressed in this work from a multidisciplinary perspective as shown in Figure 3-3.

Figure 3-3: Non-conformity propagation from a multidisciplinary approach

Relevant contributions were found in both the quality management literature and in the organization studies. This review is then structured around these two dimensions.

3.2 Manufacturing quality

3.2.1 TQM development – general concepts

Total quality management (TQM) has had considerable success in its implementation in companies. It has also been the subject of many studies in recent years.
Although concerns for quality surfaced early in the 20th century (e.g. (Shewhart, 1931)) and began to diffuse following World War II, it is only within the nineteen nineties that

corporations, consumers and government agencies in the United States and in Europe become broadly aware of the TQM concept (Sitkin et al., 1994).

Before TQM, early quality efforts, referred to as quality control, were initiated specifically as a way to improve or control the efficiency of manufacturing processes to enhance “conformance quality” (Sitkin et al., 1994). The role of the customer in defining standards to be achieved was ignored. Henry Ford for example was well known for disdaining any customer requests concerning colour: “Any customer can have a car painted any colour that he wants, so long as it is black”.

The move to TQM was motivated in part by a recognition that quality control approaches need to embrace rather than ignore insights about the social system and recognition that knowledge and learning were crucial mechanisms for sustaining a competitive advantage (Deming, 1986). They include both employees and customers as essential parts of the organizational system.

The theory of quality management has first been influenced by the contributions from quality leaders (Feigenbaum, 1982; Ishikawa and Lu, 1985; Deming, 1986; Garvin, 1986; Juran, 1988; Crosby, 1995).

Deming’s 14 points and cycle (plan, do, check, act), Juran’s quality trilogy (planning, control and improvement), Crosby’s absolutes of quality management (conformance to requirements, prevention, zero defects and cost of quality), Garvin’s quality dimensions, Ishikawa’s cause and effect diagram, and Feigenbaum’s three steps to quality (quality leadership, modern quality technology and organizational commitment); constitute the most important aspects of the TQM framework that quality gurus have recommended.

When Deming introduced TQM in the 1950s, the Japanese adopted this philosophy while the USA rejected its principles. Thus, the Japanese made a significant progress in the field of quality, resulting in the penetration of USA markets by Japanese products (Martinez-Lorente et al., 1998). Therefore, in the early 1980s, the USA utilized TQM concepts as tools to compete with Japan (Davig et al., 2003). At the same time Motorola developed the six sigma initiative: identify and reduce all sources of product variation – machines, materials, methods, measurement systems, the environment (or “mother nature”), and the people in the process (Bozdogan, 2006). This means virtually defect-free production, where a defect is defined any instance or event in which the product fails to meet a customer requirement (Pande et al., 2000). European organizations also recognized the need for a keener focus on quality and in the 1990s, TQM concepts spread to Europe (Fotopoulos and Psomas, 2009).

These ideas have influenced later studies in such a way that the literature on TQM has progressively developed, identifying various practices for effective quality management: customer-based approach, leadership, quality planning, fact-based management, continuous improvement, human resource management (involvement of all members of the firm, training, work teams, communication systems), learning, process management, cooperation with suppliers and customers and organizational awareness and concern for the social and environmental context (Tarí and Sabater, 2004).

(Dean Jr and Bowen, 1994) for example see TQ as a philosophy or an approach to management that can be characterized by its principles, practices and techniques. Its three principles are customer focus, continuous improvement, and teamwork. Each principle is implemented through a set of practices, which are simply activities such as collecting customer information or analysing processes. The practices are in turn supported by a wide array of techniques (i.e. specific step-by-step methods intended to make practices effective).
(Snell and Dean, 1992) succinctly captured the core features of TQM as it has come to be practiced: "total quality is characterized by a few basic principles- doing things right the first time, striving for continuous improvement, and fulfilling customer needs-as well as a number of associated practices".

According to (Tarí and Sabater, 2006), TQM is a quality–based strategy aimed at improving differentiation and reducing costs. TQM consists of a number of elements, which might be grouped into two dimensions: the managerial system and technical system or the "soft" and "hard" parts. The hard part includes production and work process control techniques, which ensure the correct functioning of such processes (process design, "just in time" philosophy, basic quality control tools like pareto charts, control charts etc.). The "soft" side is associated with management concepts and principles such as leadership, employee empowerment and culture. The two dimensions reflect all the issues a manager must bear in mind for successful TQM implementation. (Sitkin et al., 1994) called these two dimensions Total Quality Control (TQC) and Total Quality Learning (TQL).

Despite their distinctions, the different approaches to TQM share fundamental guiding principles. Different authors have clustered these precepts in a variety of ways, but in almost all TQM definitions a reference is made to its "soft" and "hard" side (Thiagaragan et al., 2001; Vouzas and Psychogios, 2007), stressing continuous improvement and treating the organization as a whole system.

Heightened challenges from global competitors during the past 2 decades have prompted many manufacturing firms to adopt new manufacturing approaches (Hall, 1987; Meredith and McTavish, 1992). Particularly salient among these is the concept of lean production (Womack and Jones, 1996; Womack et al., 1990). Lean production is a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management, etc. in an integrated system. The core thrust of lean production is that these practices can work synergistically to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah and Ward, 2003). A number of manufacturing practices are commonly associated with lean production, among those is Total Quality Management.

This first insight in TQM development during the last century shows how these principles have emerged from a quality inspection perspective to an integrated management system where soft aspects are just as important. More recently, it has become TQM's turn to become part of a larger management system, Lean management.

3.2.2 Linking Quality and performance: a contingency perspective

Many works subscribe to the perspective that TQM is "universal" in its applicability (Deming, 1986; Crosby, 1995; Juran, 2005), with virtually no attention to the nature of the uncertainty faced by the organization (Sitkin et al., 1994). As a result, TQM is in danger of being "oversold," inappropriately implemented, and ineffective. Indeed, this may explain some of the failures of TQM that have received attention in the popular press.

According to the concept of contingency, there is no best way to organize a corporation, to lead a company, or to make decision. Instead, the optimal course of action is contingent upon the internal and external situation. A contingency perspective implies that TQM principles and associated practices should be matched appropriately to situational requirements (Sitkin et al., 1994).

Nevertheless, when applied properly, the literature proposes several performance types or advantages that can be obtained as a result of the implementation of TQM. (Deming, 1986) pointed out that higher quality implies lower costs and increased productivity, which in turn gives the firm greater market share and enhanced competitiveness. Likewise, the European Foundation for Quality Management (EFQM) model suggests the relationship between quality management and performance. The advantages extend well-beyond quality dimensions and concern the improvement of the whole organization. (Forza and Filippini, 1998) focus on two performance advantages, customer satisfaction and conformity to specifications. (Shah and Ward, 2003) provides us with other quality performance dimensions as scrap and rework costs, manufacturing cycle time, first pass yield, labour productivity, unit manufacturing costs, customer lead time.

3.2.3 Quality management practices relevant in low-volume industries

There have been numerous studies analysing the critical factors for successful quality management implementation and its influence upon performance (Tarí and Sabater, 2004). Among these key principles of TQM, some are particularly relevant in the low-volume context, especially soft aspects. These principles are detailed further below.

3.2.3.1 *Customer orientation*

The first and most important principle according to (Dean Jr and Bowen, 1994) is customer focus. The goal of satisfying customers is fundamental to TQM and is expressed by the organization's attempt to design and deliver products and services that fulfil the customer's needs, even proactively (Blocker et al., 2011). It is the most important requirement for long-term organizational success.

In quality management, it is essential to maintain very close links with customers, in order to both identify their needs and to receive the feedback necessary to the company if it is to both understand to what extent it has succeeded in satisfying those requirements and thus to initiate the relevant improvement activities.

This principle has to be applied also in the internal customer-supplier relationship. According to (Sitkin et al., 1994), TQM is defined as the continuous improvement of processes by all employees in the organization to better meet the needs of internal and external customers. According to this definition, everyone in the organization has a customer, and a critical role of effective TQM is to ensure that incentive systems clearly hold everyone accountable to either an internal or external customer (Schonberger, 1986).

According to (Scherer and Zölch, 1995) thinking in processes and customer focus establishes a strategic guideline for straight forward reengineering of organisational units at an operational level like the shop floor. The question of customer orientation was also retrieved in healthcare (Ndubisi, 2012), where it is linked with care reliability.

3.2.3.2 *Quality commitment or orientation toward quality*

The TQM approach is characterised by an orientation towards quality, which helps to prevent problems and to produce continuous improvement of the existing situation.

This attention should permeate all levels of the company right from the top management down and all company functions (Forza and Filippini, 1998).
When the techniques of statistical quality control were first introduced in Japan, they were accompanied by a massive training program (Juran, 2005). Most early efforts focused on upper management. These training programs were well attended, and the principles of quality control were quickly disseminated. Among the principles emphasized were the close connection between quality improvement, gains in productivity, and reduction of costs, as well as the desirability of focusing on quality improvement to motivate employees (Cole, 1983; Tribus, 1985). A number of success stories demonstrated the usefulness of this approach, which soon became the standard for much of Japanese industry and the driving force behind managers' efforts to upgrade manufacturing. Firms later established training programs to teach the same principles to foremen and production workers. Several business scholars with first-hand experience in Japan have concluded that, once these principles gained wide acceptance, a strong commitment to quality emerged (Garvin, 1986). In the United States today, quality is often considered secondary to other goals. Few managers or workers are trained in the principles of quality control, and the connection between quality, productivity, and cost is often poorly understood. In these circumstances, the commitment of managers and workers to improving quality is likely to be weak (Garvin, 1986).

The orientation toward quality helps to prevent problems and to produce continuous improvement of the existing situation. This attention should permeate all levels of the company right from the top management down and all company functions. The “top management leadership on quality”, when defined as the involvement in and constant commitment of the company’s management in all its functions to quality improvement, is generally recognised as one of the fundamental elements which characterise real orientation towards quality in a company. TQM orientation towards quality is also characterised by the dedication of considerable resources in the design stage to problem prevention and to the consideration of the varying points of view of the different functions. Thus, “inter-functional efforts” are defined as the involvement and cooperation of the entire staff both individually and in groups (even inter-functional ones) (Forza and Filippini, 1998). More recently studies on quality commitment have been retrieved in the service organizations (Demirbag et al., 2012) and in healthcare (DeLisa, 2009; Holden, 2012).

3.2.3.3 *Leadership*

Management leadership is an important factor in successful TQM implementation, as documented by quality gurus (Deming, 1982; Juran, 1988). One key set of leadership skills are planning skills (Marta et al., 2005). Quality planning (e.g. objectives, plans) is necessary in order to manage quality throughout the organization (Juran, 1988; Saraph and Sebastian, 1993). In this sense, top management should act as a driver of TQM implementation by creating values, goals and systems to satisfy customers (Tarí et al., 2007).

Writers on both TQ and transformational leadership stress the communication and reinforcement of values and the articulation and implementation of a vision. It entails aligning organizational members' values with quality values of customer focus, continuous improvement and teamwork (Dean Jr and Bowen, 1994). An interesting study linking leadership to service quality has been found in the hotel industry (Clark et al., 2009). Leadership for quality is also a research interest in implementation of quality systems in healthcare (Wardhani et al., 2009).

3.2.3.4 *Training*

Many authors underline the importance of human resources in TQM. Operators are becoming "multifunctional employees" able to operate several tasks, and also carry on quality controls as well as resolve problems. For this purpose, the employees need training; this will allow them to identify and solve problems, to improve work methods, and to take responsibility for quality. This training must include technical and human aspects, such as problem solving, data analysis and statistical techniques (Ishikawa, 1985). Then, in order to improve quality, employees can be trained in the use of quality techniques and tools (Ahire and Dreyfus, 2000). Such training will generate an increased awareness of quality-related issues and can facilitate a continuous process of learning (Anderson et al., 1994). Many authors underline the importance of non-technical training in improving the system as a whole (Morel et al., 2009).

3.2.3.5 *Quality tools*

In TQM programs, data is generated through the use of a variety of quantitative analysis techniques. These tools are used to facilitate the recognition of causes of variance in production and administrative processes; and they are prerequisites for taking the actions necessary to reduce variance or errors in order to more effectively meet the customer's needs. The tools cited in the literature and used in industry are numerous and include such analytical techniques as statistical process control charts, quality function deployment, experimental design, cause-and-effect diagrams, and Pareto charts (Sitkin et al., 1994).

The TQM approach places a great deal of importance on the maintenance of process control; in other words, TQM tries to ensure that these processes do not only run as expected but also do not create problems for the future. Thus, greater attention is paid to the control of the behaviour of the processes that generate the products than to product conformity control.

To achieve this objective, use is usually made of "statistical process control"; in other words, statistical instruments are used (for example, the control sheet) in order to determine whether the machinery and the various production processes are under control or not.

Quality control and Statistical process control (SPC) have been widely studied in the literature. The first quality control activities appearing in the 1920s were mainly detection oriented. Although Shewhart invented his control charts in the 1920s, control charts were really applied only in the 1950s. Until that time companies tried to achieve quality by inspecting production lots of finished products following a certain sample plan. Using these sampling plans an estimation of the percentage of defective products can be computed. The function is to separate good batches from bad ones.

However, this way of trying to achieve quality turned out to be very costly because of inspection costs, cost for 100% selection of rejected batches, rework and scrap. The conclusion was that it was better (more efficient and more effective) to prevent failures than trying to filter them out using sampling (prevention instead of detection).

The first improvement was not to wait until a batch of products is ready but to take samples during productions using control charts. These samples are not compared with tolerances but with control limits. The function is to detect when a process is deviating (out of control) before products are produced outside specification limits, using product measures during production.

In order to learn from past errors, SPC techniques were extended with problem solving techniques such as Pareto analyses and Fishbone (Ishikawa) diagrams to find and eliminate root causes of errors made. Although not of a statistical nature, these techniques are often seen as part of the SPC-toolkit.

Even if the aim of SPC techniques is to control processes instead of products, they often are not the best tools to control inputs and process settings. The first, and unfortunately also many recent applications of SPC remain mainly output oriented (Schippers, 1998). Interested readers can refer to (Montgomery, 2007) for a global picture on the field of SPC.

Among the different evolutions of the SPC techniques, the economic design of control charts can be relevant for our purpose. It raises the question of control efficiency and its measurement (Lorenzen and Vance, 1986). A key parameter of this measurement is the detection speed. Actually, because of the sampling and false alarms, a process deviation can occur without being detected. Two variables monitor this phenomenon. They are called ATS for "Average Time to Signal" and ARL for "Average Run Length" (Lorenzen and Vance, 1986; Chen et al., 2007). They refer respectively to the average time to obtain a detection signal and to the average number of manufactured products before receiving a detection signal. These two parameters are included in the economic design of control charts and in the performance evaluation of the quality control plan.

For low-volumes and high-costs productions (aeronautics, healthcare, aerospace, dam industry), the global detection costs question is outclassed by detection speed. Actually, an ARL1 of the same order of magnitude as the lead-time can disturb the resilience of the entire production system. Thus, the decrease of impacted products (or at least potentially impacted) by the deviation is a key element that seems unaddressed by current works in the SPC field. In this context, individual run lengths have to be mastered, more than average. The economic impact of an occurrence is so high that one cannot afford to wait for multiple failure data before engaging improvement action. This would take too long to gather data and loose reactivity. SPC is thus difficult to apply in the context of low volume manufacturing. It is the same for other statistical methods like Pareto analysis. The low amount of available data often makes this analysis irrelevant. There is thus an opportunity to develop method and tools to improve detection in the low volume context.

3.2.3.6 *Lean Manufacturing practices relevant in the quality field*

Literature about Lean Manufacturing also provides relevant quality concepts for the low-volume field. As mentioned above, TQM is now embedded in a wider management system called Lean Management. Lean manufacturing principles generated by Japanese engineers in the 1940s have been the foundation for lean enterprise concepts, which have grown in popularity since the 1990s and are seen as an effective approach to cost reduction through eliminating unnecessary elements in production (Monden, 1981).

Lean production is a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management, etc. in an integrated system. The core thrust of lean production is that these practices can work synergistically to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah and Ward, 2003).

The development of the Toyota Production System (TPS) was largely unnoticed – albeit not kept as a secret – and according to Ohno, only started attracting attention during the first oil crisis in 1973. The oil crises also renewed the interest in researching the future of the automotive industry, the starting point of the International Motor Vehicle Program at MIT. After the publication of The Machine that Changed the World (Womack et al., 1990) principles such as the Toyota Production System (TPS) (Ōno, 1988) have driven the change from mass production to lean production in the Western world. This book that introduced the term 'lean production' in 1990 has become one of the most widely cited references in operations management over the last decade. Despite the fact that the just-in-time (JIT) manufacturing concept had been known for almost a decade prior, the book played a key role in disseminating the concept outside of Japan. These principles first spread in the automobile industry and its subcontractors, but have now developed in all type of industries ad even in services. "We believe that the fundamental ideas of lean production are universal – applicable anywhere by anyone" (Womack et al., 1990). According to (Holweg, 2007) it has become "one of the most influential manufacturing paradigms of recent times". Focusing on improving manufacturing, (Womack and Jones, 2003) summarised the approach into five key lean principles, namely:

1. *Specify value*. This element can only be defined by the customer.
2. *Identify the value stream*. The core set of actions required to produce a product.
3. *Make the value flow*. The method of aligning the processes to facilitate the critical path.
4. *Let the customer pull*. The customer should begin to 'pull' product on an 'as needed' basis.
5. *Pursue perfection*. Develop and amend the processes continuously in pursuit of perfection.

The authors believe that if taken as a five-step approach these principles can form a methodology for approaching any business issue.

Lean practices are generally associated with high performance in a number of studies of world-class manufacturing, e.g. (Giffi et al., 1990; Sakakibara et al., 1997). Overall, review of related research indicates that implementation of lean practices is frequently associated with improvements in operational performance measures. The most commonly cited benefits related to lean practices are improvement in labor productivity and quality, along with reduction in customer lead time, cycle time, and manufacturing costs (Schonberger, 1982; Shah and Ward, 2003)

Even if Lean thinking has been criticised on many accounts, such as the lack of human integration or its limited applicability outside high-volume repetitive manufacturing environments, its single-project focus or its lack of flexibility (Lamming, 1996; Moody, 1997; Cusumano and Nobeoka, 1998), the bulk of the literature suggests that the introduction of the lean principles have resulted in significant improvements both in customer satisfaction and operational efficiency. (Shah and Ward, 2003) quantify a 23% gain in operational performance when applying lean practices together as a system, after accounting for the effects of industry and contextual factors. They also examine the effects of three contextual factors on lean implementation and find strong support for the influence of plant size on lean implementation, whereas the influence of unionization and plant age is less pervasive than conventional conservative wisdom suggests.

Moreover (MacDuffie et al., 1996) find partial support for the hypothesis that "lean production" plants are capable of handling higher levels of product variety with less adverse effect on manufacturing performance than traditional "mass production" plant.

The work by (Jina et al., 1997) notwithstanding, we find no published work on implementation of lean in the low-volume industry, whereas some of these practices can really be relevant in this context. Paradoxically, lean manufacturing was first developed in Japan as an alternative to mass production (in opposition to Ford's model), but is now much more studied in high-volume manufacturing. We thus share the point of view of (Shah and Ward, 2003) that other environmental measures should also be considered in implementing lean practices. There is thus a research avenue in the field of low-volume manufacturing.

3.2.3.6.1 Shopfloor management

A particularly relevant principle in the context of low-volume industry is the concept of Shop floor Management.

This management concept stems out the Japanese word *Gemba* meaning "real place"- now adapted in management terminology to mean "workplace"- or that place where value is added (Suzaki, 1993). In manufacturing, it usually refers to the shop floor. *Gembutsu* means the tangible objects found at *gemba* such as work pieces in progress, scraps, tools, materials as glue, painting, and machines. *Go to gemba* is the first principle of shop floor management. This is a reminder that whenever abnormality occurs, or whenever a manager wishes to know the current state of operations, he or she should go to *gemba* right away, since *gemba* is the source of all information. Meetings concerning the shop floor are organized on the shop floor, with cross-functional teams.

This idea of gemba being the place where real value is added and the source of ideas for achieving QCD (Quality-Cost-Delay) is in direct contrast to conventional perception of *gemba* characterized by the 3K– kiken (dangerous), kitanai (dirty), and kitsui (stressful) (Imai, 2007).

(Scherer and Zölch, 1995) analysed shop floor activities and found that this level of any production enterprise is facing more and more challenges. Reality at the shop floor includes growing external demand, e.g. quality, quantities, variety and speed of products and orders. At the same time the shop floor is a heterogeneous and uncertain domain. Heterogeneity is caused through (1) technologically multifarious machines, (2) different type of production resources, (3) conflicting planning objectives, (4) different production strategies, e.g., KANBAN and make-to-order, (5) non-standardised external and interdepartmental interfaces, i.e., due date allowance, order/lot size, delivery procedures. Uncertainty is created through frequent changes of orders and unpredictable behaviour of the production system, e.g., machine breakdown or illness (Scherer and Zölch, 1995).

They analysed the information exchanges within the logistic department and the different hierarchy levels of the production line and found that: 1) information is not easy to access or is missing, (2) division of planning and execution of activities causes loss of information and unnecessary interfaces, (3) lack of work-related communication causes loss of knowledge, i.e., only communication on what to do and not how to do it.

This shows that improvement opportunities exist at Gemba regarding exchange of information, clarity, customer orientation (internal and external), involvement and problem solving.

3.2.3.6.2 Visual management

Visual management is an effective management method to provide information and *gembutsu* in a clearly visible manner to both workers and managers so that the current state of operations and the target for *kaizen* are understood by everybody. It also helps people to identify abnormality as promptly as possible (Imai, 2007).

Visual process management tools have been developed by lean practitioners as communication aids and are used to help steering operations and processes in real time (Parry and Turner, 2006). Information availability is usually not the problem; it is the communication of this information, which seems to be ineffective (Bilalis et al. 2002). Clear communication ensures information such as customer requirements, production schedules, and the aims and objectives set by management are understood across an enterprise. Lean practitioners have been developing visual communication tools, which truly drive operations and processes in real time. These systems act as an extension to metrics, and in themselves may be considered as a dynamic measurement system as they provide instant feedback and can be used to predict a probable outcome if no action is taken.

Lean manufacturing has utilised simple clear visual communication tools. The extensive use of tables and text are notable in their absence when it comes to effective communication (Parry and Turner, 2006). As Bilalis (2002) points out, the best visual aids include graphical representations, pictures, posters, schematics, symbols, transparencies and colour coding and these can be enhanced with audio signals.

Visual tools form an important part of the communication process in lean factories. A key driver of TPS is that every person involved must be able to see and fully understand the different aspects of the process and its status at any time. Making this process transparent enables immediate feedback of current status and indicates where adjustment may be required to enable a process to fulfill customer pull (Womack et al., 1990).

Common set of success factors for implementation of visual management tools are the following (Parry and Turner, 2006):

- the team must be empowered to develop its own management board (ownership)
- process is clearly presented and progress through the process is made visual
- metrics are secondary
- only value-adding information is displayed
- colourful physical visual control system is used (avoid electronic version, which are able to infinitely expand in size). The physical constraint of a board leads to greater focus on the quality and relevance of presented data.
- Having a regular pattern of meetings around the boards will ensure they evolve as an useful tool

Visual control is an underrated yet powerful tool for use beyond manufacturing. Lean practitioners have taken their knowledge of visual control learned on production lines and begun applying it to other processes. It provides transparency concerning current problems and enables an objective information sharing.

3.2.3.6.3 Jidoka (autonomation)

Jidoka is a Japanese word qualifying a device that stops a machine whenever a defective product is produced. This device is essential in introducing JIT (Imai, 2007).

In many Toyota plants there is a cord running alongside the production line. This Andon cord, when pulled by an operator, lights up a display and plays a signal unique to their station. This communicates both the problem and its location on the line so that it may be tackled before it becomes necessary to stop production (Parry and Turner, 2006).

Whether it is automated or not, the relevant principle beyond *jidoka;* is to stop production as soon as a defect is detected. In this principle, operators are responsible for quality and have the responsibility and authority to stop production if a problem is detected (McLachlin, 1997). This contributes to promote employee responsibility and involvement, as well as early problem detection.

3.2.3.6.4 Problem solving culture and structured problem solving methodology

There are two approaches to problem solving. The first involves innovation- applying the latest high-cost technology, such as state-of-the-art computers and tools, and investing a great deal of money. The second uses common-sense tools, checklists, and techniques that do not cost much money. This approach is called *kaizen*. *Kaizen* involves everybody-starting with the CEO in the organization- planning and working together for success.

The Lean philosophy encourages a real problem solving culture. Problems have to be reported as soon as they arise and displayed so that everybody is aware of them. They should not be considered as shameful and hidden. On the contrary, they should be seen as an improvement or learning opportunity. By solving the actual root causes of its problems a company improves its industrial processes. Problem solving is conducted by cross-functional teams, including operators, directly at the shop floor level.

3.2.4 Conclusion about the quality management literature

The literature review on quality management has shown the evolution of quality concepts and particularly this shift toward a “softer” approach of quality management, highlighting factors like customer orientation, quality commitment, leadership and human resource management encouraging transversal approaches to understand failures in the quality system. These concepts are embedded in the currently popular lean manufacturing concepts, which give interesting insight in methods that can help in manufacturing high-quality goods, especially in low-volume production (see Table 3-1 for a summary). Even if the concepts of reactivity in problem solving and early detection are goals of the implementation of these practices, we do not retrieve any performance indicator of this type. Thus the detection performance is not formally taken into account. Moreover, the high-variety of problems occurring in the low-volume field and their low repetitiveness, as well as long manufacturing lead times make it difficult to use standard statistical process control tools to monitor deviations. Moreover, a major stake that is not addressed by the quality literature is how to cope with disruptions while maintaining the industrial activity. Insights in this field are found in organization studies literature, particularly in literature on resilience that will be detailed in the next section. Thus there is an opportunity to develop quality and organizational methods to address this gap.

Practice	**Contribution to early detection in low-volume**
Quality tools (SPC, Pareto, Ishikawa)	Speed of detection (ARL), root cause analysis
Customer orientation	Knowing customer expectations, considering the following process as a customer
Quality commitment	Company culture, quality as a priority, time is given for quality
Leadership	Exemplarity, management support
Training	Highly competent employees (technical skills but also, quality, lean)
Shop Floor Management	Reactivity in problem solving
Visual management	Transparency regarding quality problems Information sharing
Jidoka	Source detection, employee responsibility in quality
Problem solving culture	Problems seen as an improvement opportunity

Table 3-1: Contribution of TQM and Lean practices to early detection of non-conformities

3.3 Transboundary risk management

3.3.1 Introduction

As explained in the first part of this review, disruptions are elements of the organizations' daily life (Hollnagel and Woods, 2006). According to (Jina et al., 1997) it is even more true for companies operating in low-volume manufacturing.

Analysis of quality-issues at Siemens ETHS reveals that non-conformities are generated at different stages in the realization process and propagate between these stages without being detected. This propagation is linked to failures in the articulation of the process, which is segmented into major, relatively partitioned, functional sectors. This leads to think on transboundary risks, taking into account internal boundaries within an organization.

We can talk about "transboundary risks" because of the diversity of venues where deviations occur which contribute in the end to a failure, the possible propagation of failures throughout the process and finally, the necessary work of re-articulation carried out by those involved to rectify such incidents.

This work fits into a systemic approach of risks (Perrow 1994), linked to the organizational complexity. According to this framework, the organization is both a source of risks and of reliability; it is an "open system" whose functioning is based on the exchanges between its different components.

Recent theories on risks (Schulman, 1993; Carroll et al., 2006; Barton and Sutcliffe, 2009), and resilience (Hollnagel, 2008; Tillement et al., 2008), present flexibility, "DIY"[1] and improvisation (Weick, 1993) as conditions which allow organizations to better face up to risks and unforeseen events. In the case of transboundary risks, this improvisation requires the intervention of "astute individuals" who are able to promote the circulation of information, and "fruitful interactions" between organizationally distant actors (Kapucu, 2006; Adrot and Garreau, 2010).

3.3.2 The division of work creates uncertainties, disruptions and unforeseen events

The problems of coordination and partitioning between activities are conventional problems addressed by organization theory. Many studies have focused on the sharing of knowledge (Nonaka, 1994) and have demonstrated that specialisation linked to the division of labour implies the development of different perspectives on the organization of operational modes (Bechky, 2003). Other studies have looked at the power struggles (Crozier and Friedberg, 1977) between functional departments. Finally, authors such as (Strauss, 1985) have looked at discontinuity problems linked to the division of labour. Activities are segmented, which can create disruption, incoherence and loss of information but also uncertainty as to task-related responsibilities.

Coordination can be severely affected by the division of work, the tendency to depersonalise relationships as well as physical distance or competition between occupational groups (Tillement et al., 2008). Ethnographic studies (Strauss, 1988; Star, 1989) have clearly shown the extent to which cooperation between members belonging to different "social worlds" or "communities of practice" can be difficult and will substantially influence the direction a project takes. Several origins of these tensions

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[1] Do-it-yourself

and “misunderstandings” have been identified: a high degree of bureaucratic partitioning; highly specialised knowledge which is difficult to transfer (Carlile, 2004); spatial difference (Metiu, 2004); the lack of shared objectives and meanings (Star, 1989); the existence of divergent interests (Metiu, 2004); identity-related issues (Wenger, 2000). A substantial body of literature has advanced ways in which differences can be overcome, notably through the construction of artefacts or boundary objects (Star 1989; Carlile 2004).

3.3.3 Disruptions are components of the organizations’ daily life, reliability is to cope with them

Disruptions and their informal arrangements have for a long time been seen as a problem to be eradicated. More recently, new approaches of risks present irregular variations and degradation of expected working conditions as a component of the organizations’ daily life. This theoretical change is partly due to the works developed within the framework of the studies about the organizational resilience (Weick, 2004; Hollnagel and Woods, 2006; Barton and Sutcliffe, 2009). It can be seen as a reversal of the classical perspectives about the control of risks because it means that reliability is not the absence of unforeseen events and variations, but the ability for an organization to take in charge “the irregular variations, disruptions and degradation of expected working conditions” (Hollnagel and Woods, 2006) and to cope with unanticipated dangers and uncertainties (Douglas and Wildavsky, 1983).

This highlights the necessary study of the daily work activity and of the way the different members of the organization take charge of occurring problems in the flow of their usual operations; to identify the mechanism they are able to develop in order to rebuild some order to avoid accidents. The comparison between the observation of the “normally disturbed activity” and the analysis of situations of completely unforeseen events, when sensemaking breaks down (Weick and Roberts, 1993) is particularly interesting to identify conditions of organizational resilience (Tillement, 2010). The question arises as to the way people hold on to foreseen or unforeseen events.

3.3.4 Organizational resilience

3.3.4.1 *Resilience: general concepts*

Initially, the concept of resilience belonged to the physical sciences. Resilience is a body’s ability to withstand pressure and recover its initial structure after an alteration of its shape. American psychiatrists specializing in the treatment of young children were the first to adapt the concept to describe an individual’s ability to live, succeed, and develop in spite of adverse circumstances (Morel et al., 2008). The definition progressively extends from individuals to groups and organizations, as shown in the definition of (Horne and Orr, 1997) “Resilience is a fundamental quality of individuals, groups, organizations, and systems as a whole to respond productively to significant change that disrupts the expected pattern of events without engaging in an extended period of regressive behavior” (p. 31). From this point of view, resilience is “the art of navigating the rapids” (Cyrulnik, 2001).

Quite recently, the notion of resilience has been extended to research on the reliability and safety of complex systems and defined as “the ability to manage unexpected events” (Hollnagel, Woods, & Leveson, 2006) (p. 329) (before, during, and after).

According to Wreathall, resilience is the ability of an organization (system) to keep, or recover quickly to, a stable state, allowing it to continue operations during and after a major mishap or in the presence of continuous significant stresses (Hollnagel et al., 2006). The property in question of the organization is often safety, but should also include financial performance, and any other vital goal for the organization’s well-being.

Several authors define resilience as the ability to manage great pressure as well as conflicts between safety and production objectives (Flin, 2006; Hale and Heijer, 2006). The analogy is straight with the manufacturing field where the same pressure can exist between quality and productivity objectives.

(Rerup, 2001) defines two sources of organizational resilience: anticipation and improvisation. Anticipation is the ability to predict the future in order to prevent failures. Improvisation is the ability to recombine chunks of past experience into new pattern of action. Based on the analysis of the Apollo 13 mission, he states that if an organization intends to remain resilient while coping with unexpected events, it will have to develop both anticipatory and improvisational skills.

(Morel et al., 2008) find that resilience is a form of safety (they called it Managed Safety, SM) that is very different from the form which has been, and is still, implemented to guarantee the safety of complex systems: safety through constraints (prohibitions and protections), or SC. Consequently, the whole observed safety necessarily integrates both forms of safety, but definitely not on an equal footing. They postulate the following equation:

$$\text{Observed Safety} = [SC + SM].$$

Complex sociotechnical systems (e.g., transportation, energy, medicine) require safety measures. Over the past 30 years, cognitive ergonomics has provided many description frameworks. The earliest efforts focused on the reliability of the human factor and the eradication of human error (e.g., the technique for human error rate prediction: Swain, 1964). The total eradication of human error was quickly given up as an objective (being unrealistic from a simple theoretical viewpoint), and safety naturally evolved toward a more systemic perspective (Rasmussen, 1986; Reason, 1990).

Starting in the 1990s, a large community of researchers began working along these lines, in a trend notable for three strong points: an interest in complex dynamic situations (aeronautics, railways, nuclear plants, metallurgy, military situations); an interest in fieldwork and the safety decisions actually made by operators (naturalistic decision making (Zsambok and Klein, 1997); ecological safety (Amalberti, 2001); (Hoc and Amalberti, 2007)); and an interest in limiting the traps or surprises that could arise from ill-designed automation (Billings, 1997).

The concept of resilience is a natural offspring of these original approaches, all focused on the control of safety in complex dynamic systems in the real world. The concept relates to relevant actions or strategies situated in three temporal horizons:

- The first is to imagine the catastrophe before it takes place.
- The second temporal horizon is to adapt to a critical situation and produce reasonable solutions in real time.
- The third is to manage the fallout from the accident, to the point of deciding a company’s success or failure.

Resilience provides full and adequate answers to these three levels because it allows operators to anticipate the unexpected so as to avoid it, to manage it when it does happen, and to survive the fallout after it has happened, in terms of reputation, image, and legal penalties (see, e.g., Wreathall’s, 2006, definitions).

In other words, resilience could be described as a system’s ability to resist a wide variety of demands from its whole domain of operation. The wider and better controlled the open performance domain is, the higher the level of resilience (Morel et al., 2008).

Resilience seems to be a strategic concept dealing with the improvement of safety in complex systems, since it could reconcile the notions of performance and safety rather than systematically oppose them (Morel et al., 2009).

A safety-improving philosophy called “optimization” is presented in Figure 3-4. Its objective is to increase resilience so as to maintain the system at higher performance levels (shifting of the useful work window to the right).

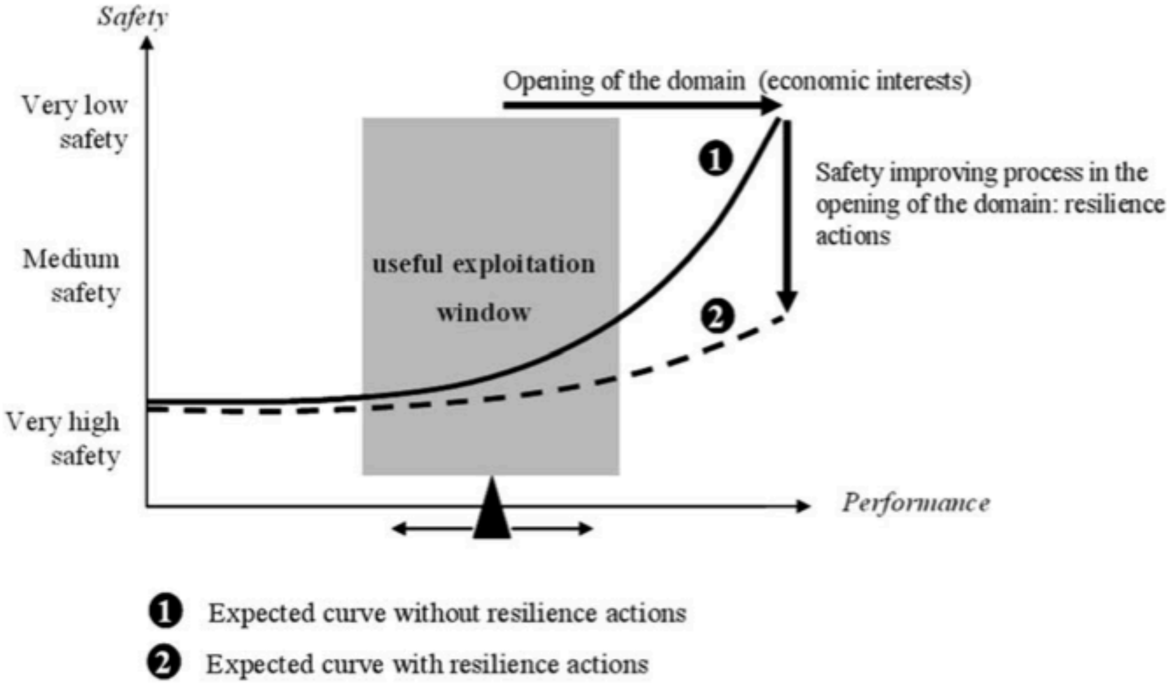

Figure 3-4: Modelling the relationship between resilience and safety- concept of the useful work window (Morel et al., 2009)

(Flin, 2006) reported that earlier accounts of air or rail disasters revealed an erosion of managerial resilience. She considered the resilience of middle-level managers as a vital component of organizational safety. She also considered three kinds of skills that characterize managerial resilience in relation to safety:

(a) Diagnosis (the ability to detect the signs of an operational drift toward a safety boundary);

(b) Decision making (the ability to choose the appropriate action to reduce the diagnosed level of threat to personnel or equipment);

(c) Assertiveness (the ability to convince other members of staff that production has to be stopped or costs sacrificed).

Resilience is related to the capacity for recognizing the problem and making a safe decision in adverse conditions (Morel et al., 2008).

In their study of professional sea fishing (Morel et al., 2008) also observed that repeated exposure to risks creates in these sailors an adaptive know-how regarding safety, much closer to the definition of resilience than to a totally rational attitude. Although the best safety response would be to stop fishing in borderline conditions, the resilient response is to go on, and develop survival skills, according to the situation (Morel et al., 2008).

Anticipating the evolution of hazards is also a key ingredient, and an accurate evaluation of one's own abilities in context is another one. Both are difficult cognitive skills, and both can be enhanced even for an experienced operator – the second of the two being the most difficult to achieve and to assist (Morel et al., 2008).

The studies on organizational resilience were first interested in High Reliability Organization (HRO) or in the analysis of disaster. However, maybe because of the powerful insight they gave in organizational functioning, they quickly raised interest beyond risk specialists, see for example works by K.E. Weick or by D. Vaughan. The works on reliability and resilience spread out their initial specialized field to the general field of organizational studies. The question of performance is an interesting entry point to study both question on reliability and resilience and economical and managerial questions. The aim of works like (Hollnagel, 2009) is to establish organizational reliability and resilience in the management field.

We believe that this concept can be particularly helpful in the quality management field, especially in the low volume industry where variations and disruptions are part of the daily life.

3.3.4.2 *Properties of resilient organizations*

Because organizational resilience is seen as a systemic property, both individual and organizational levels of analysis reciprocally influence each other (Riolli and Savicki, 2003). We believe, with (Mallak, 1998) that resilience in organizations builds on the foundation of the resilience of members of that organization. We also believe, with (Horne and Orr, 1997), that resilience at the individual level does not guarantee resilience at the organizational level.

We identify in the literature a set of common characteristics of highly resilient organizations, which can be customized for each particular domain.

- *Top-level commitment*: Top management recognizes the human performance concerns and tries to address them, infusing the organization with a sense of the significance of human performance, providing continuous and extensive follow-through to actions related to human performance, and is seen to value human performance, both in word and deed (Wreathall, 2006).
- *Just culture*: Supports the reporting of issues up through the organization, yet not tolerating culpable behaviours. Without a just culture, the willingness of the workers to report problems will be much diminished, thereby limiting the ability of the organization to learn about weaknesses in its current defences (Wreathall, 2006).

- *Immediate correction of errors and learning culture*: A shorthand version of this theme is 'How much does the organization respond to events with denial versus repair or true reform?'(Hollnagel et al., 2006; Wreathall, 2006)
- *Awareness*: Data gathering that provides management with insights about what is going on regarding the quality of human performance at the plant, the extent to which it is a problem, and the current state of the defences (Wreathall, 2006). This means detect and react to variations (Hollnagel et al., 2006) as well as the ability to interpret event and cope with complexity (Rerup, 2001)
- *Anticipation or Preparedness*: 'Being ahead' of the problems. The organization actively anticipates problems and prepares for them (Hollnagel et al., 2006). (Weick and Sutcliffe, 2001) called this a collective vigilance, i.e. the ability for a group to detect and anticipate errors thanks to a relative reluctance to simplification and an operational matter. It is a collective process based on the interactions between team members.
- *Improvisation:* Improvisation corresponds to an adaptation process (Vera and Crossan, 2005) during which individuals must "make with" available resources (e Cunha et al., 1999), and combine them in an innovative manner (Rerup, 2001) in a quasi-simultaneousness of decision and action (Moorman and Miner, 1998). Improvisation is often associated with the concept of "DIY". In crisis situations, actors have to rapidly adapt and improvise (Weick, 1993).
- *Flexibility*: It is the ability of the organization to adapt to new or complex problems in a way that maximizes its ability to solve the problem without disrupting overall functionality. It requires that people at the working level (particularly first-level supervisors) are able to make important decisions without having to wait unnecessarily for management instructions (Hollnagel et al., 2006).
- *Opacity*: The organization is aware of the boundaries and knows how close it is to 'the edge' in terms of degraded defences and barriers (Wreathall, 2006).

As well as knowing what is the present state of safety in the organization, it is important that the organization has available appropriate levels of resources (particularly reserves) that can react to sudden increasing challenges or the sudden onset of a major hazard – (Reason, 1990) has referred to this capability as providing 'harm absorbers' – analogous to shock absorbers in mechanical systems. These resources can be material, such as providing additional staff to cope with significant challenges (e.g., dedicated emergency response teams), or they can be design-oriented, such as building in additional times for people to react (some have called this 'white time') so that plant and

management personnel have time to reflect on the nature of the challenge and take appropriate responses.
On the matter of defences, of course one class of defences exists in the form of all the barriers that are built in. These have been extended by people such as (Fujita and Hollnagel, 2004) to include more abstract (non-visible) barriers, such as standards, codes of conduct and procedures, and the like (Wreathall, 2006).

The fundamental characteristic of a resilient organization is that it does not lose control of what it does, but is able to continue and rebound (Hollnagel et al., 2006). A system is in control if it is able to minimise or eliminate unwanted variability, either in its own performance, in the environment, or in both. The link between loss of control and the occurrence of unexpected events is so tight that a preponderance of the latter in practice is a signature of the former (Hollnagel and Woods, 2006).

A number of common conditions characterise how well systems perform and when and how they lose control, regardless of domains. These conditions are lack of time, lack of knowledge, lack of competence, and lack of resources (Hollnagel & Woods, 2005, pp. 75-78).

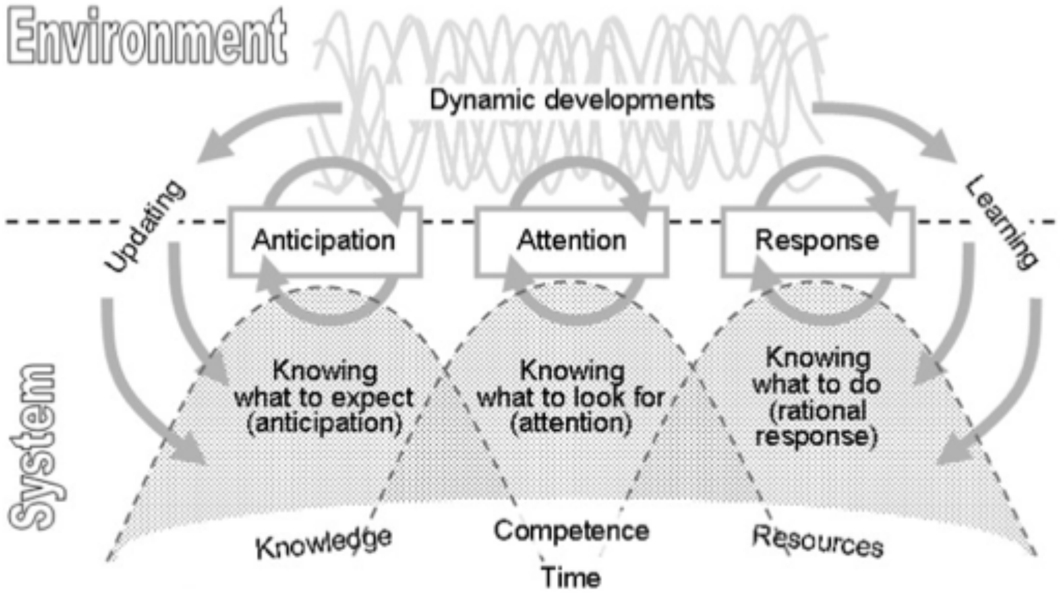

Figure 3-5: Required qualities of a resilient system from (Hollnagel et al., 2006)

A resilient system must have the ability to anticipate, perceive, and respond. Resilience engineering must therefore address the principles and methods by which these qualities can be brought about (Hollnagel and Woods, 2006). A resilient system must be proactive; flexible; adaptive; and prepared. It must be aware of the impact of actions, as well as of the failure to take action.

3.3.4.3 *Introducing resilience in complex systems*

The literature provides different helpful insights on how to introduce resilience in complex systems.

- A first suggestion by (Morel et al., 2008) is to proceed within the limits of a well-regulated work domain where operators still retain some autonomy rather than by strict protocol-type guidelines (free flight). This is also suggested by (Adrot and Garreau, 2010) who recommend a bounded room of manoeuvre in order to foster collective improvisation, or (Rerup, 2001) who advocates for a formal structure with flexible rules which provide "wiggling room" to improvise in case of an emergency.
- A second suggestion is to develop know-how to face destabilizing situations. This can be done by anticipation scenario or simulation, as suggested by (Morel et al., 2008), or by fostering competence exchange with experts or between professions (Couix, 2010). Developing knowledge and competencies is one of the major stakes of resilience, especially developing decision capacities in conflicting situations where there is a trade-off between performance and safety or quality.
- Situation awareness is considered by (Endsley and Garland, 2000) to be at the core of anticipation capabilities of individuals. Cross-training is presented by (Couix, 2010) as a key element to develop situation awareness and thus anticipate mistakes, which is an essential characteristic of resilient systems. Cross-training involves training each team member on the duties and tasks of the other team members. Results of (Bolstad et al., 2005) suggest that cross-training may lead to improved situation awareness, because knowledge of tasks of the other team members enables to better anticipate the evolution of the situation.
- Remove systems, processes and artifacts that get in the way of work being performed safely and effectively – the data gathering from the workers about 'things that get in the way of working safely' is one example. This same need applies at the organizational levels as well as the workers' level (Wreathall, 2006).

Creating resilience engineering involves the development of several elements to create a set of tools that can, together, be used to enhance safety in the face of constant stresses and sudden threats (Wreathall, 2006).

3.3.5 Crossing boundaries to re-articulate work and build a multi-situated viewpoint

In the course of normal activity as facing unforeseen events, organization breakdowns always need to be reduced. According to Strauss, alignment is always necessary to ensure business continuity and what Strauss calls the work of articulation, which must accommodate the different actors whilst the action is underway. Articulation requires

negotiations and arrangements. Actors will align their definitions of the situation, or at least make them compatible around a shared objective.
Building on the analysis of operation of a nuclear power plant, (Vidal et al., 2009) show that the cooperation modes tend to evolve depending on the situation. In normal situation, the cooperation occurs by means of articulation of individual contributions, generally supported by operational procedures, in order to lead to an effective collective performance. But during problem-solving situations, when operators have to deal with unexpected events, in which a quick decision concerning the unit is needed, prior to the eventual action cooperation takes the form of confrontation of individual contributions.

This articulation work can be the responsibility of individuals (boundary spanners) or objects (boundary objects) which allow meaning and language to be shared, along with the alignment of practices, learning and people's understanding of other actors' roles.

3.3.5.1 *Boundary objects*

(Star and Griesemer, 1989) developed the concept of boundary object to analyse the nature of cooperative work in the absence of a consensus. They define boundary objects as an analytic concept of those scientific objects, which both inhabit several intersecting social worlds and satisfy the informational requirement of each of them. They are flexible enough to adapt to local needs, yet robust enough to maintain a common identity across boundaries. They materialize and carry in the interaction an invisible infrastructure made of standards, categories, classifications, and conventions proper to one or several social worlds (Bowker and Star, 2000).
The notion of boundary object initially comprised three components: interpretive flexibility; arrangements in terms of information structure and work processes; and the dynamic at play between highly- or poorly-structured used of objects. The use of the concept of boundary objects has mostly concerned the first component, allowing it to operate as a support for heterogeneous translations as a knowledge integration mechanism and as a mediation in the coordination process of experts and non-experts (Trompette and Vinck, 2009). However it does not allow to take into account the entire conceptual model (Vinck, 2010). Boundary objects are the ingredients of action, a mean of "representing, learning about and transforming knowledge to resolve the consequences that exist at a given boundary" (Carlile 2002; Carlile 2004). Adaptability of the object and its relative interpretative flexibility promotes various buy-ins, transformations and adaptations by social groups who are prepared to cooperate in a permanent to-ing and fro-ing between the consensual form and its deviations. They "provide a lingua franca for exchanges" and facilitate cooperation (Star and Griesemer,

1989). But boundary objects are also temporal, build in action, and subject to reflexion and local adaptation. Objects become boundary objects at any given time in a given situation.

Based on certain form of actions and cooperation, (Star and Griesemer, 1989)suggested four types of boundary objects. This list was not intended to be exhaustive.

- Repositories: ordered ‘piles of objects with the advantage of modularity
- Ideal type: abstract and vague, thus adaptable and good enough for all parties
- Coincident boundaries: common objects with same boundaries but different internal contents
- Standardized forms: devised as methods of common communication across dispersed work groups

(Carlile 2002) defined three characteristics of good boundary objects:

- They establish a shared syntax or language for individuals to represent their knowledge.
- They provide a concrete means for individuals to specify and learn about their differences and dependencies across a given boundary.
- They facilitate a process where the individuals can jointly transform their knowledge.

The role of boundary objects is to help establish a boundary infrastructure (Bowker et S. L Star 2000) or boundary process that individuals use to manage knowledge across a given boundary. Management of these objects, including construction of them, is conducted by communities only when their work coincides. The objects thus come to form a common boundary between worlds by inhabiting them both simultaneously (Star and Griesemer, 1989). When participants in the intersecting worlds create representations together, their different commitments and perceptions are resolved into representations. This resolution does not mean consensus. Representations contain the trace of multiple viewpoints, translation and incomplete battle. The production of a boundary object is thus one mean of satisfying potentially conflicting sets of concerns.

Some authors studied how some objects failed to perform as boundary objects. (D’Adderio, 2004) study of software systems usage show that product and database structures failed to perform as boundary objects for lack of flexibility to localization. (Sapsed and Salter, 2004) shows the limitations of project management tools as boundary objects within dispersed or global programs or teamwork, where there is no opportunity for face-to-face interactions and/or ambiguous lines of authority.

3.3.5.2 *Boundary spanning individuals*

The notion of a boundary spanning individual was developed by (Tushman and Scanlan, 1981b) as part of development projects. These individuals are described as an effective resource for collecting and transferring information between organizational boundaries. The phenomenon of boundary-crossing is often informal and confers power and status upon the boundary spanner. The role of the boundary spanner is to (re)construct alignment (Cholez, Tillement, and Reverdy 2009). Its activities of rectification and informal coordination have been identified by crisis specialists as factors of resilience. According to (Adrot and Garreau, 2010), in a highly uncertain situation, the boundary spanner contributes to coherence between parties of the organization through generation of fruitful interactions between actors giving them both an action framework and room for manoeuvre.

Many authors have studied the role of boundary spanners in different situations, especially during emergency and crisis. We identified in the literature different proprieties of boundary spanners, which are prerequisite for performing a boundary spanning activity. As we can see in Table 3-2, the role of the boundary spanner is, first of all, to foster interaction at boundaries between groups or organizations, which can be teams, departments, customer or suppliers, etc. He is thus very well connected to the external. He is also very well connected internally, that's why he is at the centre of information transfer. But he does not transfer raw information; he does a work of translation, consolidation and summary for the team. His technical skills and organization knowledge are recognized, which confers him to a high degree of legitimacy. Among his interpersonal competencies, he is above all a trustworthy, reliable and respectful person. As explained by (Weick, 1993), these characteristics are essential in crisis situation, where morale is one of the only remaining things when sense collapse. In a problem solving situation his coordination and mediation skills are particularly valuable and allow work continuity. They are an interface between separated professional universes. They are able to detect a large part of errors and mistake, and in that sense are strong resilience pillars.

Characteristics	References							
Communication	Well connected internally = able to disseminate new information and ideas (Tushmann 1981)	Communicate to the other units on a regularized basis (Aldrich 1977)	Brokers, bridge and help overcome information asymmetries and breakdowns. (Van der kleij 2010)	Informational intermediaries and catalysts (Williams 2002)	Basic and effective oral, written and presentational communication skills (van der kleij 2011)	Skills (training) to communicate with different external areas (Tushmann 1981)	Play a significant role in effective communications in emergency and crisis management (Kapucu 2006)	
Technical skills	Technically competent in their unit (Tushmann 1981)	Technically competent individuals (Tushmann 1981 b)	Competent in multiple domains (Levina 2005)	Organizational experience (Tushmann 1981 b)				
Coordination/ federation skills	Glue between social groups (Williams 2002)	Foster cooperation and information exchange, reduce communication costs (Williams 2002)	Coordinating task activities with other groups, (Ancona 1992, marrone 2010)	Reticulist (networking skills) (Williams 2002)	Policy entrepreneur : to connect problem to solution and to mobilize resources and efforts in the search for successful outcomes (Williams 2002)	Shaping and facilitating network form (van der kleij 2010)	Promote interorganizational networks (before crisis) (Kapucu 2006)	Foster interorganizational communication and (Kapucu 2006)
Mediation / negociation	Mediation /negociation (Aldrich 1977)	Skills of understanding, empathizing and resolving conflict (Williams 2002)	Conflict resolution (Marrone 2010)	Influencing, negotiation, brokering especially in non hierarchical situations (Williams 2002)	Facilitate the sharing of expertise by linking two or more groups of people separated by location, hierarchy, or function. (Levina 2005)	Managing complexity and interdependencies (Williams 2002)		
Interpersonal competencies	Trustworthy (van der kleij 2010)	Building and sustaining effective personal relationships, (van der kleij 2010)	Self-confident (van der kleij 2009)	An easy and inviting personality (van der kleij 2011)	Engage with others, effective interpersonnal competencies (williams 2002)	Trust (Williams 2002)	Respectful, reliable, tolerant, diplomatic, caring, committed (Williams 2002)	Sensitive to social cues (Caldwell and O'Reilly 1982)
External connection and representation	Well connected externally = to external information areas (Tushmann 1981)	External representation (Aldrich 1977)	Proportion of time spent with outsiders (Aldrich 1977)	Number of outsider contacts (Aldrich 1977)	Representing the team to stakeholders, (Ancona 1992, Marrone 2010)	Seeking information from outside experts (Ancona 1992, Marrone 2010)	Maintaining the organization's image and enhancing its social legitimacy = making the organization visible (Aldrich 1977)	Link their organization with the external environment (Kapucu 2006)
Information processing	Defence against information overload, selecting information (Aldrich 1977)	Filters and facilitators in information transmit (Aldrich 1977)	Summarize/consolidate/translate/ interpret information (Aldrich 1977)	Information processing (Aldrich 1977)	Make decision about information gathered (Kapucu 2006)			

Table 3-2: Characteristics of boundary spanners

Boundary spanners and boundary objects could organize the emergence and the achievement of a multi-situated attention that guarantees a better understanding of the complexity of the situations. Opposing to Perrow who associates complexity with increase of the risks, Weick asserts that to reduce risks, the organizations should complicate themselves to encourage redundancies. Multi-disciplinary groups, cross-department teams should be encouraged to get people used to interact and communicate (Brion, 2005).

3.3.6 Conclusion on transboundary risk management

Resilience engineering is a concept gaining support particularly in the safety field. Even if many authors argue that it is applicable beyond the safety domain (for example in health care), few works if none have been retrieved on resilience in the manufacturing quality field, where it could be seen as the ability of the organization to cope with disruptions in their daily activities (altering process or product quality), to maintain an acceptable level of quality despite quality issues and crisis. Building on the model of (Morel et al., 2009) there is an opportunity to consider resilience as a strategic concept for improvement of quality in complex manufacturing systems, since it could "reconcile" the notions of performance and quality. It could also bring relevant insight how to enable companies to manage quality issues in their normal activities and during crisis. This concept is particularly relevant in the low-volume field, where flexibility and adaptation are key requirement in conducting business.

We also find in the literature two interesting concepts, which contribute to the work of articulation and thus support resilience, the use of boundary object and boundary spanners. Both can ensure continuity especially in crisis situations. Nevertheless little evidence was found of the limit of boundary spanning activities although the case presented here highlights risks linked to a resilience only based on boundary spanners that can be overflowed or counterproductive.

CHAPTER 4 METHODOLOGICAL APPROACH

4.1 Choice of methodology

There are different methodological approaches for research in operations management as described by (Flynn et al., 1990; Karlsson, 2008), among which include modelling and simulations, surveys, action research, and case research. Each one has its advantages and drawbacks, but the better adapted to our research project is the case study methodology.

4.1.1 Why case study is adapted to our research

Case research is the method that uses case studies as its basis. It is a research strategy that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident (Yin, 2009). Case study has consistently been one of the most powerful research methods in operations management, particularly in the development of new theory. It also has high validity with practitioners, the ultimate users of research (Voss et al., 2002). A case study typically uses multiple methods and tools for data collection from a number of entities by a direct observer in a single, natural setting that considers temporal and contextual aspects of the contemporary phenomenon under study. The goal is to understand as fully as possible the phenomenon being studied (Meredith, 1998).

(Meredith, 1998) cites three outstanding strengths of case research:
(1) Relevance: The phenomenon can be studied in its natural setting and meaningful, relevant theory generated from the understanding gained through observing actual practice.
(2) Understanding: The case method allows the questions of why, what and how, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon. Such questions can lead both to theory testing, but more importantly to theory development.
(3) Exploratory depth: The case method lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood.

Case studies can be used for different research purposes such as exploration, theory building, theory testing and theory extension/ refinement see Table 4-1.

Purpose	Research question	Research structure
Exploration Uncover areas for research and theory development	Is there something interesting enough to justify research	In-depth case studies Unfocused, longitudinal field study
Theory building Identify/describe key variables Identify links between variables Identify why these relationships exist	What are the key variables? What are the patterns or links between variables? Why should these relationships exist?	Few focused case studies In-depth field studies Multi-site case studies Best-in-class case studies
Theory testing Test the theories developed in the previous stages Predict future outcomes	Are the theories we have generated able to survive the test of empirical data? Did we get the behaviour that was predicted by the theory or did we observe another unanticipated behaviour?	Experiment Quasi-experiment Multiple case studies Large scale sample of population
Theory extension/ refinement To better structure the theories in light of the observed results	How generalizable/universal is the theory? Where does the theory apply?	Experiment Quasi-experiment Multiple case studies Large scale sample of population

Table 4-1: Matching research purpose with methodology (Voss et al., 2002)

To sum up, this methodology is well-adapted to our research purpose because:

- We intend to study a complex and contemporary phenomenon, non-conformity propagation in manufacturing, in its natural settings, the production floor of the industrial company
- This propagation phenomenon has unclear boundaries, as it can run beyond the manufacturing stage, that’s why we call it transboundary. Moreover, boundaries between departments should also be considered in the problem-solving stage.
- This methodology provides high value for practitioners, who are the main sponsors of the research through the CIFRE agreement, which also implies an involvement of the researcher in the company’s day-to-day activities. This allows for rich observation, interaction with participants and full data access.
- How and what questions drive this project, what implies a need for exploratory study as well as for theory building, for which case study is particularly appropriate.

4.1.2 Researcher status

During field investigation, the position of the researcher in the study environment has a major impact on the collected data (Junker, 2004; Yin, 2009).

The researcher status defines the role that the researcher will play in the industrial field so as the distance he has with its object of study (Surbier, 2010). (Junker, 2004) defines four different roles for the researcher according to his involvement in the company's activities (see Table 4-2).

	Researcher status	**Researcher's identity**	**Involvement of the researcher**
Comparative involvement: Subjectivity and sympathy	Complete participant	Concealed to the participant of the situation under study	Full involvement in the company's daily activities
	Participant as observer	Not wholly concealed, kept "under wraps"	Light involvement
Comparative detachment: objectivity and empathy	Observer as participant	Publicly known	No involvement but researcher on the premises
	Complete observer	Concealed	No interaction with the stakeholders of the situation under study

Table 4-2: Reasercher status and its implications, adapted from (Surbier, 2010)

(Karlsson and Åhlström, 1995) point out that the researcher who wishes to conduct a longitudinal field study of a process faces the problem of access. They see the clinical perspective as one means of overcoming the access problem. This method is characterised by active participation in formulating and observing organisational change. As a result, researchers are able to gain access to rich data denied to other approaches. The main difference from consulting is that the clinical researcher is interested in the results of the interventions and in drawing generalizable conclusions from these results. The consultant is more interested in giving recommendations and implementing them. The approach adopted here is also close to the observation *in situ* of daily functioning of the organization proposed by (Journé, 2005). This method combines rigor and opportunism in order to understand how actors maintain an unexpected situation under control.

The researcher adopted different statuses during the five stages of the project[2]. This project can globally be qualified from clinical research, except for stage 5 in which this aspect is only partial. As a company member in the manufacturing quality department,

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[2] These five stages are described in the following section.

the researcher was fully involved in the company daily activity and had access to all the needed data. The operational mission of the researcher was first of all the implementation of lean manufacturing in the company. She developed a specific lean training and trained all the employees of the factory. She participated in the development of lean tools in the factory (waste hunting, supermarket and kits, problem solving methodology). A second mission was the animation of interdisciplinary working groups on major quality problems (tightening, document, etc.). However, the involvement in the different stage had varied from partial to full. The identity of the researcher was partially revealed. Concerning stage 5, the study was conducted in a different factory of the same company. Here, the researcher adopted a status of *Observer as participant* as she wandered around the company without taking part in its daily activities but was able to interact with stakeholders and to access all the necessary data. The identity of the researcher was publicly known.

All the stages, except stage 3, were conducted as longitudinal field study. This corresponds to an in-depth study of an organization over time implying significant researcher commitment and organizational access. This method is characterized by active participation in formulating and observing organizational changes. As a result, researchers are able to gain access to rich data denied to other approaches. Stage 3 was conducted as a retrospective case, which allows collection of data over a year.

This type of involvement can induce an observer bias. As explained by (Voss et al., 2002), personal biases can shape what you see, hear and record. A too deep involvement, particularly in real-time longitudinal studies may threaten the objectivity of the observer who becomes closer to the organization, the people and the processes. The researcher may become an advocate, not an observer. For example, it is reported that students of innovation are notoriously prone to a strong “pro-innovation” bias (Leonard-Barton, 1990). There are a number of ways of countering this such as the use of structured research protocol, or the presentation of evidence in a verbatim form rather than summarised.

A single case study is subject to limits in generalizability and several potential biases, such as misjudging the representativeness of a single event, exaggerating the salience of a datum because of its ready availability (Leonard-Barton, 1990). Multiple cases augment external validity and help guard against observer biases, that’s why the proposition was tested in a second industrial context.

In retrospective studies (like stage 3), the danger is not so much that one may surrender to ones own biases as that one may unconsciously accept those of the informant. The phenomenon under study is seen through the lenses of the informants chosen, and the researcher may take the story as told, without questioning interpretations. In order to reduce this bias in the retrospective study conducted in stage 3, information was systemically clarified and corroborated by experts.

4.2 Research protocol

4.2.1 Overview of the project stages

The project was decomposed in five different stages or sub-cases that were conducted sequentially or parallel (see Figure 4-1). The first stage was an exploratory study focused on quality problems encountered by the firm, and their management. This stage allowed the researcher to develop a research framework and research questions. The second stage of the project was another exploratory study directed toward the analysis of the quality controls on the line to identify weaknesses and opportunities for improvement (the question was: why propagation?). This stage led to a control map of all formal and informal controls performed by operators on the line. It raised the question of the performance of these controls and more generally of the detection system. Two paths were followed to answer the question of propagation. On the one hand, the improvement of the detection system, and on the other hand the analysis of organizational design to foster resilience. The first path led to the evaluation of the permeability of the quality controls (analysing defects passing through controls). This enabled the development of the propagation-controlling tool (stage 3). This tool was then confronted with empirical data on non-conformities in stage 4. Finally it was tested in another industrial context to validate its relevance (stage 5). The second path (stage 3' and 4') investigates how resilience mechanisms can contribute to reducing the propagation of non-conformities. Among these mechanisms, lean training has been particularly studied. These mechanisms are then evaluated in a different industrial context.

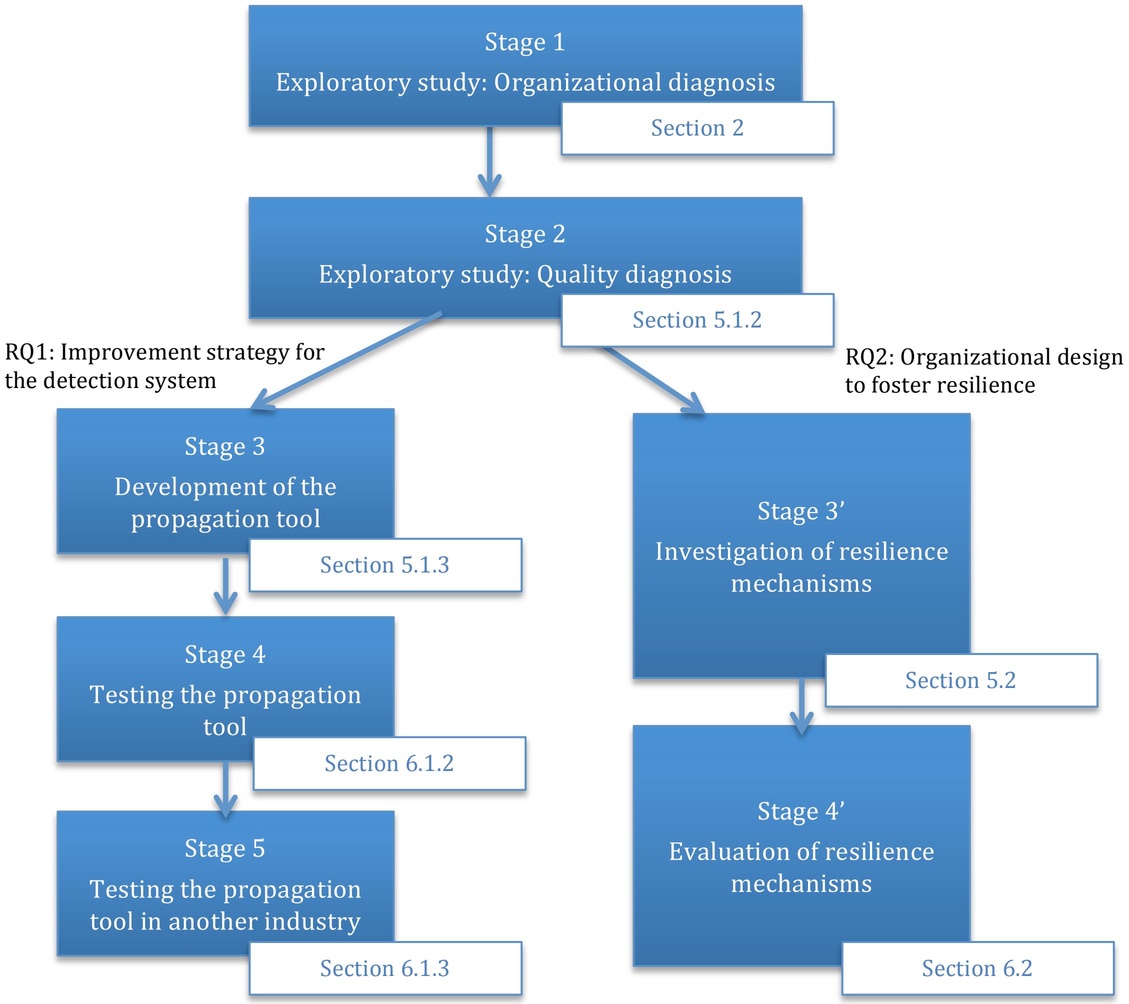


Figure 4-1: Overview of the project stages

4.2.2 Research protocol

4.2.2.1 *Stage 1: Exploratory study*

This first exploratory study was conducted on the basis of direct observations and interviews:

- Direct observation was performed during a one-month immersion onto the production line, in order to learn the basics of the product and the assembly. This assembly training happened directly on the line with operators and enabled informal interactions with them.
- Twenty-four semi-structured interviews were performed in parallel on different actors:
    - top managers (10)
    - production managers (8)
    - quality team (6)

The topics discussed were production flows, encountered quality problems, feelings about quality, and relationships with the quality department. The interviews were written up in text files. All the interviews were compared by department and summarized in a grid (see Appendix I).

This exploratory stage resulted in the in the research framework displayed in Figure 4-2 and the associated research questions presented in chapter 2. The centre of the observed problem is that non-conformities can propagate between the process steps and even until the end customer, having an impact on the organizational performance. The question here is first to find relevant quality tools and methods to limit this propagation and then to identify the contribution of organizational resilience to the non-conformity propagation in the context of low-volume manufacturing.

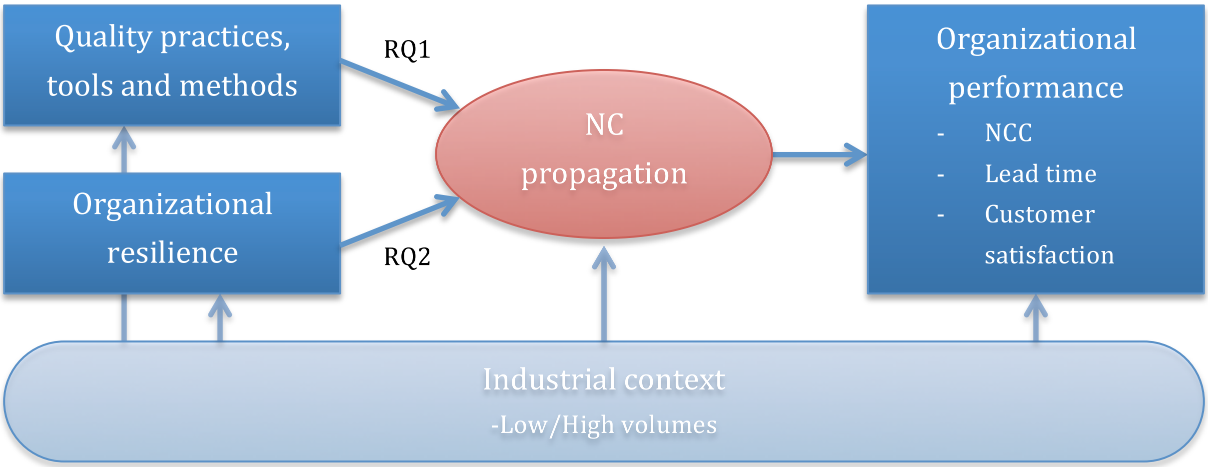


Figure 4-2: Research framework

4.2.2.2 *Stage 2: Exploratory study*

This second exploratory study focussed on the link between quality practices, more specifically quality controls, and propagation. During this step, data was collected by direct observations on the production line during one month and by structured interviews of operators and quality technicians (20). The interviews were conducted face-to-face with a questionnaire (see Appendix II). The topics were the controls performed during the operation. The results were coded, simplified and recorded in a database (see Appendix III) and lead to a control mapping and an analysis of the value-added of controls.

4.2.2.3 *Stage 3: Development of the propagation tool*

This retrospective study was based on forty non-conformity records issued over a year. The information gathered was clarified and verified by interviews of the quality team, quality supervisors, and production managers. Data was reduced and coded in a database (see Appendix IV). The goal was to identify for each non-conformity, the detection step and the generation step. This stage led to the development of the propagation tool.

4.2.2.4 *Stage 4: Testing the propagation tool*

The goal of this stage was to test the tool developed in the previous stage with real time data. During this stage, data on non-conformities were collected through formal non-conformity records, quality meetings and also from direct involvement in animation of problem solving groups and training. These exchanges were particularly enriching concerning employees problems and feelings and will be detailed in the following section. Data was reduced and coded in the same database as in step 3 (Appendix IV). This stage led to a refinement and a validation of the tool in the context of low volume manufacturing.

4.2.2.5 *Stage 5: Testing the propagation tool in another industrial context*

This study was then conducted in another Siemens factory, on a production line manufacturing pressure transmitters for process industries. Around 140 000 devices are produced every year, with a very high customization level (around 20 000 possible variants).

The objectives of this last case were:

- Test the proposed tool in another industrial context (relevance of the tool) and automation possibility (theory refinement)
- Compare the non-conformity management processes between the two companies to compare their resilience level and explain differences

The research protocol adopted here can be decomposed in four steps:

1. Pre-visit preparation (1 month)

Our main interlocutor in the factory was the quality manager. He provides us with relevant data to prepare our visit:

- information on the company and the product
- production line implantation
- quality data on errors detected on the line over the past two years
- assembly procedures

Thank to this data, and three phone exchanges, we were able to provide a first retrospective analysis on quality errors over the past three months.

2. On-site data collection (1week)

The quality manager helped us to identify relevant interlocutors for our study. These persons were the production line manager, the shop floor manager, the quality team of the line, the method team, and the coordinator operator.

A first presentation of the study was made to these people on the first day to explain the objectives and the expected results.

Then a week was spent on the line to make direct observations of the work and especially the management of non-conformities. The most relevant information was provided by the repairman and the coordinator.

Results of the observations and interviews were discussed daily with the quality manager and the quality technician on the line to complete the analysis and to clarify and verify the data collected as recommended by (Voss et al., 2002).

3. Tool adjustment and testing (1 week)

Thanks to our observation and analysis of the non-conformity records we were able to adapt and test the propagation tool developed in Grenoble. This was done with the quality technician of the line. Daily exchanges were organized to understand the requirements of the company and to adapt the tool to their operational needs.

During the two weeks direct observations and interviews were conducted to evaluate the resilience level of the organization, i.e. how the organization managed quality disruptions while maintaining an acceptable level of quality output, and to identify resilience mechanisms. Questions were directed toward the management of the quality issues, particularly the coordination mechanisms between the different departments in normal and in problem-solving situations. The respondents were also asked about the difficulties experienced in the communication and coordination process, particularly between departments.

4. Post-visit stage

The two weeks were closed with a presentation of the results to the same people as in the first presentation. Both results on the propagation distance and on the resilience were shared and discussed. Recommendations were given on the two topics.

The company implemented some of them during the following months.

Another presentation was made in Grenoble with the same departments in order to present the case and enrich the comparison between the two cases.

4.2.2.6 *Stages 3’ and 4’: Lean Training*

The analysis of organizational mechanisms that foster resilience and transversality has been developed mainly on data collected by operational immersion of the researcher, particularly in conducting lean training. The objective of the lean training was to train all the employees in Lean philosophy and basic lean tools that were being implemented in the factory at that time. The training was based on a serious game, which reproduced a little production, and in which participants were asked to compose a production team with its support services, in order to deliver products to the customer with the required quality and in a given time. The game-based approach is widely used in both industry and university (Faria et al., 2009; Bassetto et al., 2011) to support training in production systems, particularly in lean manufacturing (Badurdeen et al., 2009): the latter identified gaps in the simulation design among which a lack of emphasis on the soft skills and lack of realism. The game presented here was designed to bridge these gaps by focusing on the same documents, problems and problem-solving process, as in the real assembly line.

This simulation game reproduced the situation of the real production, in a mastered environment on a small scale and with reduced time constraints and stakes. This enabled the researcher to study phenomena that cannot be studied otherwise within a short time frame. This opportunity was used to study the non-conformity generation and management and also cooperation between departments in problem solving. Data were collected through direct observation of participants in the game and from questionnaires (see Appendix V). The researcher was also the facilitator in the game what can induce biases due too the high involvement as detailed in section 4.1.2. Moreover the solicitations of the participant during the game can prevent the researcher from stepping back and seeing the big picture. To overcome this bias videos of the game have been recorded for 3 sessions. Another limit of the game was the very short operation times for the lego (in minutes), compared to the long assembly time in the real production (in hours). These short times induce for some of the participants an additional stress.

A first session was organized for the top management (12 people), who were then asked to co-animate the following training sessions. Each top manager co-animated a minimum of two sessions and up to eight sessions. All employees were trained within 9 months in 41 training sessions of one day for the management, quality and industrial teams, and a half-day for the other employees. Data concerning the training is summarized in Table 4-3.

Lean training
41 training sessions
14 One-day sessions, 27 half-day sessions
385 trained employees (99%)
1 training session for a supplier
Satisfaction questionnaire
Comprehension questionnaire
Duration: February 2010 to October 2011

Table 4-3: Lean training characteristics

4.2.2.7 *Summary of the project stages*

Table 4-4 sums up the different stages of the research project detailed in the previous sections.

	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
Location	Grenoble	Grenoble	Grenoble	Grenoble	Haguenau
Duration	Oct.-Nov. 2009 (2 months)	April 2010 (1 month)	May-Oct. 2010 (6 months)	March- July 2011 (4 months)	Dec. 2011-Jan. 2012 (2 months)
Researcher status	Participant as observer	Participant as observer	Complete participant	Complete participant	Observer as participant
Type of study	Longitudinal	Longitudinal	Retrospective	Longitudinal	Longitudinal
Objective	Exploratory First diagnostic of the company on the topic of non-conformities management	Exploratory Analysis of the quality controls on the line (the question was: why propagation?).	Theory building Design of a quality tool to control non-conformities propagation	Theory testing Validate the relevance of the tool with a real time study	Theory testing Generalization of the tool
Method and data sources	Field investigation, direct observation, interviews (20)	Direct observation and interviews	Retrospective analysis of quality issues over a year (reports analysis and interviews)	Real time analysis of non-conformities (reports analysis, direct involvement)	Real time analysis of non-conformities (direct observation and interviews)
Results	Definition of the research question and research framework	Control map Identification of weaknesses and improvement opportunity in the control system	Definition of the propagation indicator and of the tool	Validation and refinement of the tool for the context low-volume	Validation and refinement of the tool for the context high-volume

Table 4-4: Summary of the research stages

4.3 Evaluation of the research project

4.3.1 Reliability and validity in case research

A difficulty researchers conducting case studies in operations management often face is the common misperception that case research is not 'rigorous' because many of the variables may not be mathematically quantified and the independent variables cannot be manipulated at will (Meredith, 1998). But as (Meredith, 1998; Voss et al., 2002; Yin, 2009) note, the case study method is guided by the same overall principles and follows as well-defined rules of evidence and proof as the rationalist methods.

It is particularly important to pay attention to reliability and validity in the case study research (Voss et al., 2002). According to (Yin, 2009), it can be evaluated through different aspects: construct validity, internal validity, external validity and reliability. These dimensions are summarized in Table 4-5.

Test	Definition	Case study tactic	Stage of the research
Construct validity	The extent to which correct operational measures are established for the concept being studied	Use multiple source of evidence Establish chain of evidence Have key informants review draft case study report	Data collection Data collection Composition
Internal validity	The extent to which conjectured relationships actually exist	Do pattern matching or explanation building (understand why)	Data analysis
External validity	The extent to which a study's findings can be generalized beyond the immediate case study	Use replication logic in multiple case study Consider the possible effect of organizational context	Research design Data analysis
Reliability	The extent to which a study's operations can be repeated, with the same results	Use case study protocol Develop case study database	Data collection

Table 4-5: Reliability and validity in case research, adapted from (Voss et al., 2002)

The evaluation of the reliability and validity of our findings will be discussed in chapter 6.

4.3.2 Evaluation methods of our propositions and indicators

After evaluation of the research project we propose to evaluate our propositions on different basis. We thus define indicators for the two sides of our proposition.

First, concerning the quality management practices, methods and tools to reduce the propagation of non-conformities that we will propose in chapter 5, we defined the following indicators:

- Non-Quality costs of the company
- Production Lead time
- Average propagation of non-conformities

Secondly, we propose to evaluate factors and methods that should enhance organizational resilience in their contribution to:

- Reactivity in problem solving
- Transboundary coordination (inter-department)
- Sustainability of the problem solving

4.4 Conclusion

This research project has been conducted following a case study methodology. Five sub-cases or stages in this research project have been identified and are presented in this chapter, as well as the research protocol. The involvement of the researcher in the studied company enabled her to do a 'clinical research' and to overcome the issue of data accessibility. It also enabled the researcher to gather useful insight for practitioners, the primary sponsors of the project. Evaluation criteria of the research are presented in this chapter and will be discussed regarding our results in chapter 6.

CHAPTER 5 PROPOSITION

This chapter aims at presenting the proposals to master the non-conformity propagation in an industrial company operating in an Engineering-to-Order context. The chapter is divided into two sections based on the two approaches used to answer the research question. In the first approach, this work is interested in the shop floor because it is the location where propagation materializes. The proposal is then directed toward the improvement of the detection system. In the second approach, the proposal steps back at the organization level, particularly at department interfaces, and examines how non-conformities can propagate across the organization's boundaries and which resilience mechanisms can be set up to avoid this propagation.

5.1 Improvement strategy for the detection system

5.1.1 Objective

Non-conformities propagation can generate huge costs for companies, and surprisingly this parameter is not monitored by default in quality standards. The target of the quality control system is to stop defects as early as possible, ideally where they have been generated. For a specific control device, the detection speed is a major performance indicator. Other indicators are overall costs, sensitivity to small disturbances and quantity of false alarms (Lorenzen and Vance, 1986). There is an opportunity to adapt the concept of permeability of a protection mean from the safety field to a case of low volume production in which it cannot afford to wait until a failure impacts several products to adjust detection. In the aeronautic field for example, it is easy to understand that no one can wait until several airplanes are impacted by a potentially harmful defect before acting. The detection system has to be monitored on-line. The objective of this chapter is to present tools to measure and improve performance of protection systems, in the case of low volume industries, thereby answering the first research question:

> RQ 1: How can the performance of the protection system of a low-volume industry be characterized?

This question is addressed in this chapter through a second exploratory study presented in section 5.1.2 and through a propagation model detailed in section 5.1.3.

5.1.2 First approach: control stream mapping

The first exploratory study presented in chapter 2 has highlighted that the quality problems encountered by the company often came from other departments and passed through various process stages before being detected. This finding questions the performance of the protection system of the company. Various mechanisms are actually in place to avoid quality issues in areas such as procedures, training, controls, tests, etc.

In the assembly phase, the principal protection mechanism is control. Many controls are required for each operation, but given the amount of quality problems detected in the last assembly step or during on-site installation, these controls might be porous. A second exploratory study was thus launched in the first company under study to understand why the controls in place were inefficient.

The objective is to analyse the added value of quality controls in order to rationalize them and to find local “breaches”, i.e. locations in the process where controls are inefficient or non-existent and thus allow defects to pass through. This study aims to propose a mapping of all controls performed during the assembly in a visual manner in order to understand and question the coherence of the global control plan.

5.1.2.1 *Data collection*

The relevant data for the analysis of controls has been established with the quality experts and are summarized in a questionnaire that was used as an observation guide (see Table 5-1). The data was collected through direct observation of the production line for one month of full-time involvement and via interviews of operators (20). The production line under study employs around forty operators in two shifts. It is dedicated to one of the three products manufactured by the plant.

An excel database has been constructed to register data from the questionnaires. The database counted 332 entries for the whole assembly process. A single operation can include up to 30 controls.

Questions	**Description**
Process step	Localisation in the assembly process
Name of the control and reference	Instruction reference, if existing
Type of control	- Formal/informal, - Auto-control yes/no, - Visual/manual/dimensional…
Object	What is controlled? (Component, sub-assembly, tool, etc.)
Control mean	Equipment, operator, quality supervisor, etc.
Control frequency	How many controls per day/week
Traceability	Yes/no If yes specify the type of record (following sheet, drawing, IT, etc.)
Control duration	Time spent to perform the control
Response to what kind of risks	Assembly, electrical, mechanical, safety, etc.
Controlled sample	%
% Failed	*%*
Action if failed	Reparation on the line, scrap, return to previous step, derogation, etc.
WIP before control	Number of units waiting for control
Relevance of the control (evaluated by the operator)	*Less important, important, vital…* ➔ Will enable an evaluation of the gap between quality specification and operators' perception.
Can the control be skipped?	If yes, under which circumstances?
Comments	

Table 5-1: Questionnaire on controls

5.1.2.2 *Data analysis*

The database obtained through the data collection was not immediately usable. Raw data principally contained too many details and was not homogeneous. A first work of simplification was thus necessary. The main simplifications are detailed below:

- *Clustering* of repeated controls for the same operation. This principally concerns controls linked to tightening and greasing. These operations are repeated many times for each assembly operation. We reduced the entries in the database from 332 to 216.
- *Homogenisation* of control titles, i.e. definition of a list of control types.
    - *Components*: verification of the components before assembly (reference, quality, quantity)
    - *Tightening:* control of the torque tightening
    - *Assembly conformance:* component assembly in accordance with the specifications (orientation, alignment, right component at the right place, etc.)
    - *Electrical tests*: High voltage, electrical continuity, partial discharge level, etc.
    - *Mechanical test*: routine tests for circuit breaker and commands (open/close, speed,etc.)
- *Classification* of risks for the final product
    - Electrical (flashover, partial discharges, electrical continuity, overheating)
    - Functional (disfunctioning of the material)
    - Gas tightness (risk to loose gas)
    - Pressure (safety risks linked to the presence of pressurized gas in the material)
    - Fit of the assembly
    - Production stop
    - Conformity to specification
    - Aesthetic
- A column was added to localize the origin of the potential error being controlled. Actually all controls are not autocontrol. It means that conformance of an operation can be controlled later in the process.

The simplified database is presented in Appendix III.

5.1.2.3 *Mapping proposition*

Any proposition for a control mapping was found in the literature. The inspiration for a control mapping came from Value Stream Mapping (VSM) representation. A value stream is a collection of all actions (value-added as well as non-value-added) that are required to bring a product through the main flows, starting with raw materials and ending with the customer (Rother and Shook, 2003). These actions considered the flow of both material and information within the overall supply chain (Abdulmalek and

Rajgopal, 2007). The ultimate goal of VSM is to identify all types of waste in the value stream and to take steps to try and eliminate them. Taking the value stream viewpoint means working on the big picture and not on individual processes. VSM is a visual tool using a predefined set of icons to express all activity, which exposes problem and wastes, and highlight improvement quickly. According to (Wee and Wu, 2009), VSM has the following benefits:

- It provides a complete and visual flow (material and information) to support decision making
- It highlights and exposes the wastes
- It demonstrates the close linkage between information and material flows
- It develops a plan to eliminate waste and to sustain continuous improvement

This tool is particularly inspiring in the sense that it proposes a global picture of the process. The control mapping aims at providing this kind of picture. The philosophy of waste identification in a visual manner is the same. In the proposed development of a control mapping, process boxes from the VSM are replaced by control boxes. Control boxes contain selected information from the database. A typical control box is represented in Figure 5-1.

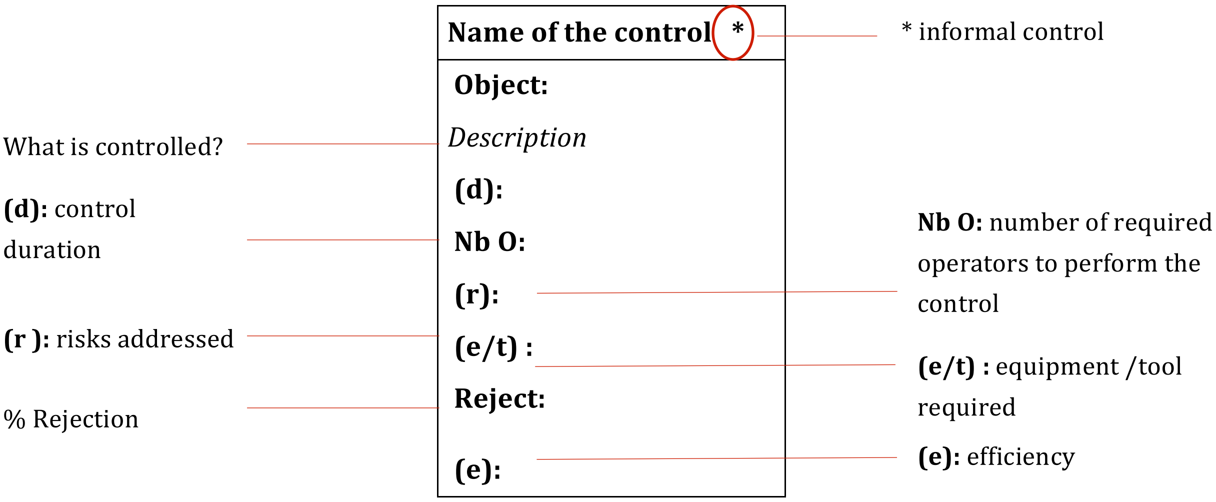


Figure 5-1: Standard control box

For each operation, controls are represented as a flow to consider the real process order and precedence constraints among the different controls for the same operation. Controls can then be sequential or parallel.

The mapping also considers the positioning of the control regarding the complete operation. Three types of controls are identified. First, the controls performed at the entrance of the operation. These controls are mainly directed toward conformity of parts before assembly, verification of the conformity of operations performed at previous assembly steps, or verification of traceability documents. The second category of controls are those performed in the course of the operation, for example tightening controls, electrical measures, etc. Finally, the third category of controls is performed after the operation. These controls are for example document controls, visual verification, or tests on the whole sub-assembly. We propose to distinguish by colour on the mapping the controls performed before, during and after the operation. An example of the succession of controls for a given operation is displayed in Figure 5-2. This contributes to the visualization of the control load pro operation and gives insight in the action opportunities concerning the positioning of controls. Actually controls performed in the course of the assembly operation cannot be moved contrary to the controls performed before or at the end of the assembly for which this opportunity exists.

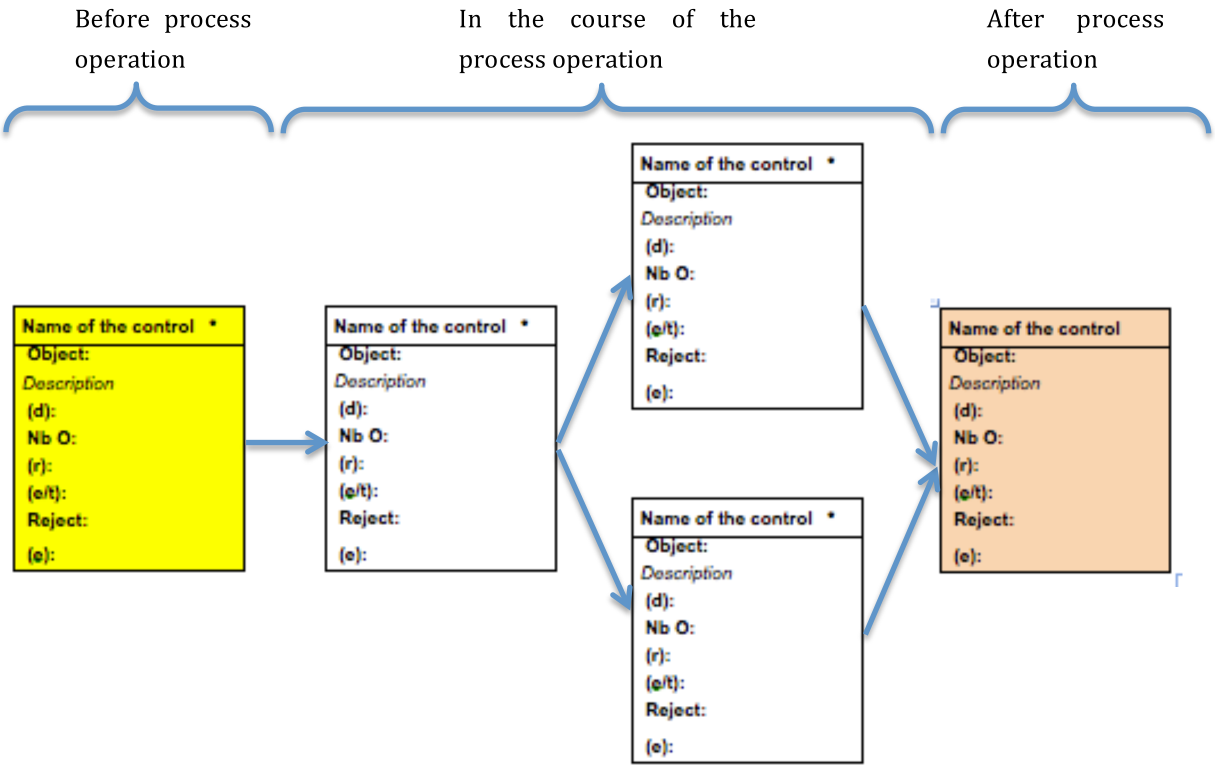


Figure 5-2: Control sequence for one process operation

The mapping also displays information on WIP between operations. Like in a classical VSM, WIP are displayed by triangles. Material flow is represented by arrows between operations see Figure 5-3.

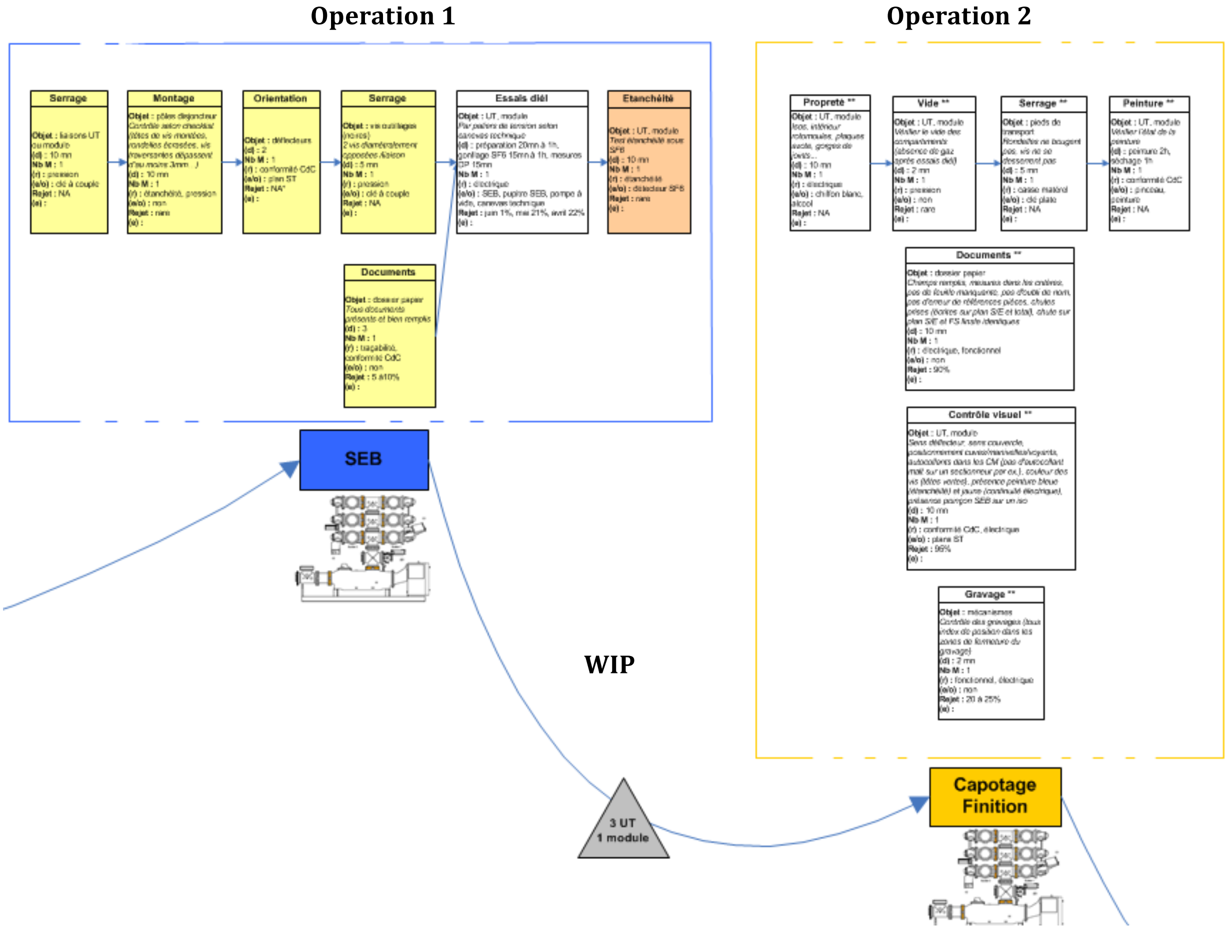


Figure 5-3: WIP between operations

Finally, Figure 5-4 gives an overview of the complete control mapping. Operations are grouped in three categories: pre-assembly (above left), assembly and post-assembly (above right) operations.

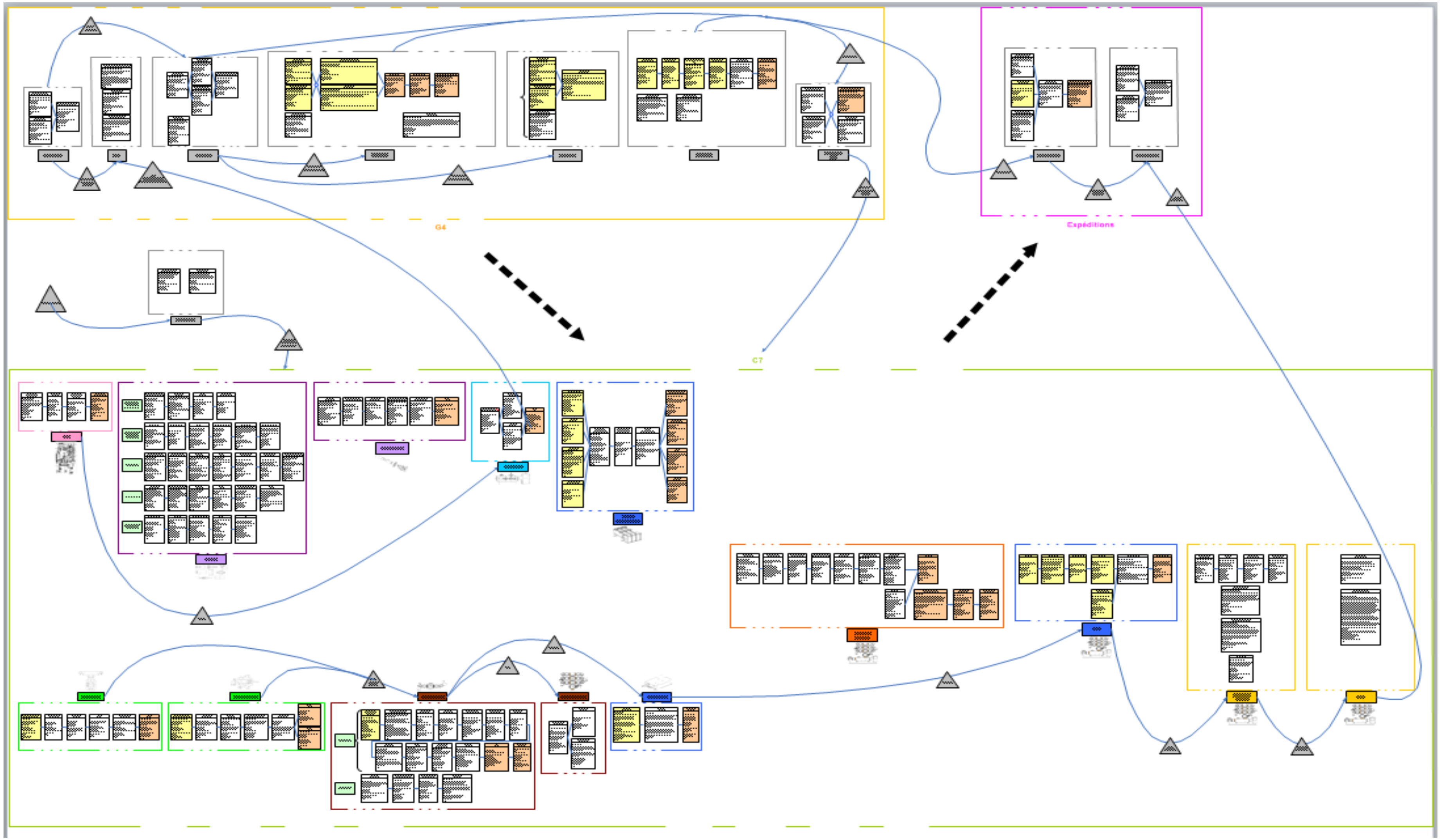


Figure 5-4: Control mapping for the whole assembly process

5.1.2.4 *Findings*

The mapping presented above gives an overview of the whole control plan of one product, from the components reception to the shipment of the final product. The goal is to identify sources of waste or of inefficiency and improvement opportunities.

This mapping gives different information:

- It first gives real data on the controls performed on the shop floor. This will enable the control plan expert to identify gaps between theory and real field practices. This approach of real data is encouraged by lean experts as presented in section 3 (Imai, 2007).
- The proportion of formalised controls. This will show the level to which the company is relying on the operator's competencies.
    - On the 216 observed controls, 102, i.e. nearly half of them are not formalised. They are based on the operator competencies and past experience of encountered problems. No traceability is asked.
    - These controls are however deemed necessary by the operators. This highlights a gap between what is required and what is really done on the shop floor. This also presents a risk linked to the human dependency on the controls and the absence of standards, which can induce high levels of variations between operators and thus high variability in the outcomes. Particularly this can help to understand why a problem suddenly appears although nothing apparently changed in the process or in the product.
- The number and duration of controls for a given operation. This will help identify balancing issues between operations in term of controls. Actually, the lean philosophy led to the balancing of the global workload between operations. We propose to do the same with the control load.
    - The control load is very important for many operations. Operators are required to perform up to thirty controls for the same process operation. These controls are moreover mainly relying on operator vigilance.
    - Some process steps required several controls before the beginning of the operation. These controls are often redundant and should be examined case by case. In the case of the final electrical test this can be explained by a need for double verification due to the high level of safety risks. Here no simplification can be undertaken. However, in other cases, redundant controls can be eliminated. They often result from an incremental building of the control plan during the product lifecycle. Controls are often added at a given time in response to a specific context or problem encountered. Once in place, these controls are often not questioned even if

    context changes. The mapping can help to question the global control plan and to re-establish coherence between the control distribution and between the different operations.
  - A guiding principle in the balancing of controls between operations is the lean principle of source quality. According to this principle, the control has to be performed as close as possible to the process, even before the beginning of the process (kit preparation for example).
- Redundancy of controls. The mapping will show if a control is performed several times.

In the case presented here, the analysis of the mapping also gives insights into the particular characteristics of quality controls in low-volume manufacturing.

- *Redundancy*. Many controls are repeated due to safety issues linked to the product. This characteristic also appears in the literature in the analysis of High Reliability Organizations (HRO) like nuclear plants, or railway (Tillement et al., 2008).
- *Incrementally adjusted.* The control plan is adjusted incrementally in the course of the product lifecycle to respond to environmental changes or specific customer requirements.
- *Not fully documented.* A wide range of controls relies on the operator know-how and knowledge of previous failures. Even when the control is formally required, its scope can be very large. The operator is often asked for a global control of the part or sub-assembly that do not underline the critical control points. Without specific knowledge he may miss a critical issue.
- *Heavy workload.* The large amount of control represents an important part of the operator’s work and time. This requires a high level of vigilance for the operator.

5.1.2.5 *Conclusion: Definition of the propagation indicator*

The control mapping gives a global overview of the control system. It is particularly helpful in the analysis of the coherence of the global control plan. It shows that control operations are an essential part of the assembly and are really demanding in terms of time and operator vigilance.

This high level of controls relying on operators seems to be a characteristic of the low-volume and high variability manufacturing. This is also intensified by the safety issues linked to the nature of the product.

The difficulty in this analysis is to quantify the added value of a control. This added value is linked to the efficiency of the control or to its capacity to release uncertainty on

controlled products as explained by (Bettayeb et al., 2010). In the low volume context, it is impossible to get probabilistic data on control efficiency. Moreover, the analysis of the control mapping and the associated database revealed that many problems where detected far away from their origin.
In order to evaluate this efficiency we propose thus a bypass strategy consisting of evaluating the permeability of the control or of a process step. The permeability corresponds to the amount of undetected problems for a given control or operation. It can be evaluated thanks to the available data on quality problems. The permeability is linked to the propagation of defects. The propagation distance of a defect is then defined as the number of process steps a defect run through before being detected.

The choice of the indicator was guided by the search of simplicity in the calculation and of a meaningful indicator, simple to understand.
A time indicator would have been disrupted by waiting times in the process, in WIP for example. Moreover, the process step indicator is easy to understand and to communicate. It can be immediately linked with the value added to the product for each operation.

The underlying assumption is that the average propagation distance is a relevant performance indicator of the global protection system and also of the organizational resilience. Actually, defects that propagate highlight weaknesses in the protection layers' system. The propagation distance is also closely linked to non-conformity costs through the increasing number of impacted products and/or amount of induced rework. Finally, the decrease of the defect propagation is coherent with "Lean Manufacturing" features such as source control or auto-control. The proposition is thus to monitor this propagation with a control chart and to consequently implement improvement actions of the protection system.

The mapping only takes into account one kind of protection layer or one dimension of the protection system, i.e. the quality controls. However, the protection system of an industrial company is composed of various mechanisms aiming at preventing the occurring and propagation of non-conformities. These mechanisms are for example training, fool proofing, procedures, etc.
The proposition presented in the following sub-section aims at broadening the scope of the protection system to these mechanisms.

5.1.3 Second approach: propagation model and improvement methodology

As explained previously, the propagation of non-conformities can generate huge costs for companies and surprisingly this parameter is not monitored by default in quality standards. The target of the quality control system is to stop defects as early as possible, ideally where they have been generated. The previous section showed that the performance of the controls could not be evaluated a priori and that a work around strategy is needed. Propagation is linked to missed detections, therefore the strategy adopted in this work consists of evaluating the permeability of the controls to estimate their efficiency.

The objective of this study is to evaluate the propagation path of non conformities on the production line under study in order to validate the relevance of the propagation indicator presented in the previous section and thus to present a methodology to control the propagation distance of non-conformities along the value stream.

5.1.3.1 *Data collection and analysis*

This analysis is based on 41 quality reports issued over a year. These reports concerns major quality issues of different nature. They can concern assembly mistakes, errors linked to tools, to documents, to cleanliness, etc. They are registered in a standard format in an IT tool (see Appendix for an example of Quality report). This retrospective data was verified by interviews of the quality team. The objective of the interviews was principally to clarify the generation and detection location of problems.

Relevant data were summarized in a database (see appendix). The assembly process was split in 15 operations and a propagation distance was calculated for each non-conformity. The intuition about the high level of propagation was confirmed by the analysis. For the 41 non-conformities under study, the average propagation distance reaches 6 process steps, i.e. 40 % of the process length.

This analysis drove the development of the propagation model presented in the following section.

5.1.3.2 *Modeling assumptions*

The propagation model presented in this section relies on different simplifying assumptions detailed below:

Assumption 1: The defect concept is not linked to a particular failure mode, but to any potentially harmful event that can alter the product performance. Given the wide range of failure modes and their low repetitiveness, all type of defects have to be aggregated in the model.

Assumption 2: The manufacturing system is supposed to be composed of operations.

Assumption 3: The chosen distance unit is the number of steps in the manufacturing process. This unit has been chosen in order to be coherent with the production system notion and is based on the assumption that both occurrence stage and detection stage of a defect can be identified. It implies a stable decomposition of operation over the period.

Assumption 4: The notation implies that every detection operation is included in a production step and that every production step includes a detection operation.

Assumption 5: For a given production system, the propagation distance follows a normal distribution.

5.1.3.3 ***Notations and key concepts***

Each product P that is manufactured has a specific process plan.

The process plan of P is the set: {Op1, .., OpN}, with N the length of the process plan.

$i \in [1;N]$ is the operation index.

e identifies a particular non-desired event.

$E_T = \{e \text{ observed during the duration } T\}$, the set of non-desired events observed during the period T.

Defects are supposed to be generated at an operation Op_{i_e} and detected at Op_{j_e} with $N \geq j_e \geq i_e$.

In consequence, the defect travels a distance of $d_e = j_e - i_e$ operations throughout the manufacturing system.

Operations cannot detect every non-desired event. It depends on the type of defect and the required device used to monitor the process. For each operation Op_j there is a permeability indicator denoted by p_j. The permeability of an operation j is increased by 1 each time a non-desired event goes through this operation, while a detection system was supposed to catch it.

This distance can be visualized in a matrix named C crossing generation and detection locations. C is illustrated Figure 5-5. In row are the operations that generate the non-conformities while in column are operations that detect the non-conformities. The matrix C stores each defect trajectory.

$$c_{ij} = \begin{cases} 1 \text{ if the non desired event occurs at } Op_i \text{ and has been detected at } Op_j \\ 0 \text{ in other cases} \end{cases}.$$

C is a null matrix except in one position.

By construction of the matrix C, the distance between the 1 in the matrix C and the diagonal visually represents the distance d_e. C becomes a visual tool. As a defect cannot be detected before being generated, the bellow-diagonal part of the matrix is greyed. This matrix has been inspired by an adaptation of the process matrix presented by Shippers (Shippers, 1999). Instead on focusing on links between products characteristics and process factors, the matrix is only centered on processes for both detection and generation.

Each time a defect occurs, a matrix C is generated. It is possible to compute another matrix Q that sums matrix C over a given period of time. $Q = \sum_t C$ and has for a general term the following expression $q_{ij} = \sum_t c_{ij}$.

e^* is a type of defect that can occur several times in a given period of time. A matrix $Q_{e^*} = \sum_t C_{e^*}$ can be built that focuses on defect of type e^*.

With matrix C and Q, and their comparison for each type of non-desired event e, it becomes possible to qualify the performance of the overall process control system. C is employed at the event level, while Q and Q_e, are employed at the system level. C, Q and Q_e are illustrated in Figure 5-5. The considered process is made up of six steps. The event monitored by the matrix C occurs at step 3 and has been detected at step 5. The matrix Q_e reports that occurrences of event e always happen at step 3. However the phenomenon has been detected once at the same step, one time at step 4, 6 times at step 5 and 4 times at the last manufacturing step. The matrix Q stores every occurrence of defect and detection. For instance the operation number 3 generates ten defects that have been detected at step 4 for eight of them, one at operation 5 and one at the last manufacturing operation.

$$C: \begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & & 0 & 0 & 0 & 0 & 0 \\ 3 & & & 0 & 0 & 1 & 0 \\ 4 & & & & 0 & 0 & 0 \\ 5 & & & & & 0 & 0 \\ 6 & & & & & & 0 \end{array} \qquad Q_e: \begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & & 0 & 0 & 0 & 0 & 0 \\ 3 & & & 1 & 1 & 6 & 4 \\ 4 & & & & 0 & 0 & 0 \\ 5 & & & & & 0 & 0 \\ 6 & & & & & & 0 \end{array} \qquad Q: \begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & 0 & 3 & 0 & 7 & 0 & 0 \\ 2 & & 1 & 2 & 1 & 0 & 5 \\ 3 & & & 1 & 8 & 6 & 4 \\ 4 & & & & 1 & 2 & 1 \\ 5 & & & & & 1 & 6 \\ 6 & & & & & & 0 \end{array}$$

Figure 5-5: Illustration of matrix C, Q^e and Q

5.1.3.4 *Use of the control concepts*

A two level strategy is proposed to decrease the propagation distance. As illustrated in Figure 5-7, it is composed of a system dimension and of an event dimension. The two parts of this strategy can be run independently.

5.1.3.4.1 System level strategy

At the system level, the method consists in monitoring propagation distances in the Q-matrix for a given time period. Improvement actions are based on the permeability analysis. The matrix Q is a key element in identifying breaches in the protection system and highlighting location for potential improvement actions, i.e. where efforts should be focused on.

$Q_{.j} = \sum_i q_{ij} = \sum_i \sum_t c_{ij}$ is a raw vector that retrieves the number of detections of non-desired events for each operation over a given period.

$Q_{i.} = \sum_j q_{ij} = \sum_j \sum_t c_{ij}$ is a vector column that retrieves the number of generations of non-desired event for each operation over a given period.

$\overline{D} = \frac{\sum_{k=1}^{card(E_T)} d_k}{card(E_T)} = \frac{\sum_{k=1}^{card(E_T)} j_k - i_k}{card(E_T)}$ $\overline{D}$ is the average propagation distance

The ranking of $Q_{i.}$ retrieves worst, non-desired event generators, while the ranking of $Q_{.j}$ retrieves the best detectors. The follow-up of each non-desired event allows building a global picture on the permeability of each operation. The following algorithm provides insight on how to systematically organize these computations:

```
(1) For $k = 1$ to $card(E_T)$
(2)     identify $j_{e_k}$
(3)     identify $i_{e_k}$
(4)     computes $d_{e_k}$ and $C$
(5)     update $Q_{e_k}$ and $Q$, computes $Q_{\bullet j}$ ,$Q_{i\bullet}$ and $\bar{D}$
(6)     For $m = i_{e_k}$ to $j_{e_k} - 1$
(7)         if $e_k$ was detectable on $op_m$ then
(8)             $p_m = p_m + 1$
(9)         end if
(10)    End For
(11) End For
(12) Print the vector of permeability for each operation, worst generators and best detectors
```

Defects that ran through step 2 without being detected

	1	2	3	4	5	6	Qi
1	0	3	0	7	0	0	10
2		1	2	1	0	5	9
3			1	8	6	4	19
4				1	2	1	4
5					1	6	7
6						0	0
Qj	0	4	3	17	9	16	$\bar{D}$ = 90/49 = 1,84
Permeability	10	7+8=15	7+6+18 =31	5+10+3 =18	5+4+1+6 =16	0	$\bar{P}$ = 15

Figure 5-6: Permeability algorithm application

An illustration of this algorithm is presented in Figure 5-6. The matrix presents $Q_{.j}$, $Q_{i.}$, the permeability and the mean distance. For instance, line 2: 9 defects were generated at the second operation during the observation period. 1 has been immediately detected, 2 after 1 step, 1 after 2 steps, 5 at the end of the process. Column 2, controls settled at operation 2 have observed 4 defects. These controls also have missed the 7 defects initiated at operation 1 and detected at operation 4. The global permeability for the second step is then 9-1+7=15. The general formulation of permeability of the x^{th} operation is given by the following formula:

$$Permeability(x) = \sum_{\substack{i<x \\ x \le j \le N}} q_{ij}$$

The average distance in the example of figure 3 is 1.775 operations. This means that on average a defect crosses about 30% of the manufacturing process before being detected. At the system level the average propagation distance illustrates the performance of the global control system. The goal of the control system is (1) to reduce the propagation of defects and thus the average diagonal distance in order to have a matrix that is as diagonal as possible and (2) to reduce the permeability of the control plan.

5.1.3.4.2 Event level strategy

The event level consists in a real time analysis based on the monitoring of the propagation distance for each defect with a control chart and the implementation of actions of improvement based on the analysis of each defect propagation path.

At the event level, the key idea is that each process control presents breaches. It is normal that the distance of every event is not null i.e. $\forall e \in E_T, d_e \neq 0$. However abnormal breaches can generate a special cause and increase the distance. The event level control is proposed through the monitoring of d_e with individuals and moving range control charts. Individual-X / Moving Range charts are chosen here because measurements cannot be grouped into rational subgroups, and it is more convenient to monitor actual observations rather than subgroup averages. Each subgroup, consisting of a single observation, represents a "snapshot" of the process at a given point in time. Control charts for individual measurements use the moving range of two successive observations to measure the process variability. The idea is to follow the individually measured propagation distances for each defect and the difference from one point to the next (moving range) over a given timeframe and to set upper control limits (UCL) over which an alarm is triggered and an improvement action is taken. These upper control limits are defined in accordance with (Montgomery, 2007) when they are different enough from the process limit N (number of process steps). If UCL are too close from N, another dimension is proposed and corresponds to the half of the process steps. This level is the highest acceptable limits by the quality experts of the company under study. It has to be adapted to each specific context with regard to the cost of the propagation.

$$UCL_D = \begin{cases} \overline{D} + \frac{3}{d_2} * \overline{MR} & \text{if UCL << N} \\ \frac{N}{2} & \text{if UCL} \approx \text{N} \end{cases}$$

$$UCL_{MR} = \begin{cases} D_4 * \overline{MR} & \text{if UCL << N} \\ \frac{N}{2} & \text{if UCL} \approx \text{N} \end{cases}$$

$\overline{D}$: average propagation distance
$\overline{MR}$: mean of the moving ranges
d2: anti-biasing constant for n=2 (Montgomery, 2007)
D4: anti-biasing constant for n=2 (Montgomery, 2007)
N: number of process steps

This method is a trigger for improvement actions. Lowering the upper control limits will lead to more actions, but this is not a problem knowing that the aim is to improve the control system.

Figure 5-7 summarizes the two-level strategy proposed to decrease the defect propagation distance. This strategy will be carried out on two case studies in chapter 6. The proposed method is then two fold:

- At the event level, each time an error occurs and is detected, an alarm of an abnormal phenomenon is triggered. The associated quality control has to be corrected.
- At the system level, each time a defect occurs it is stored in the matrix. Permeability and generator indicators are updated. At the end of a predefined period, actions are performed on major detractors and holes.

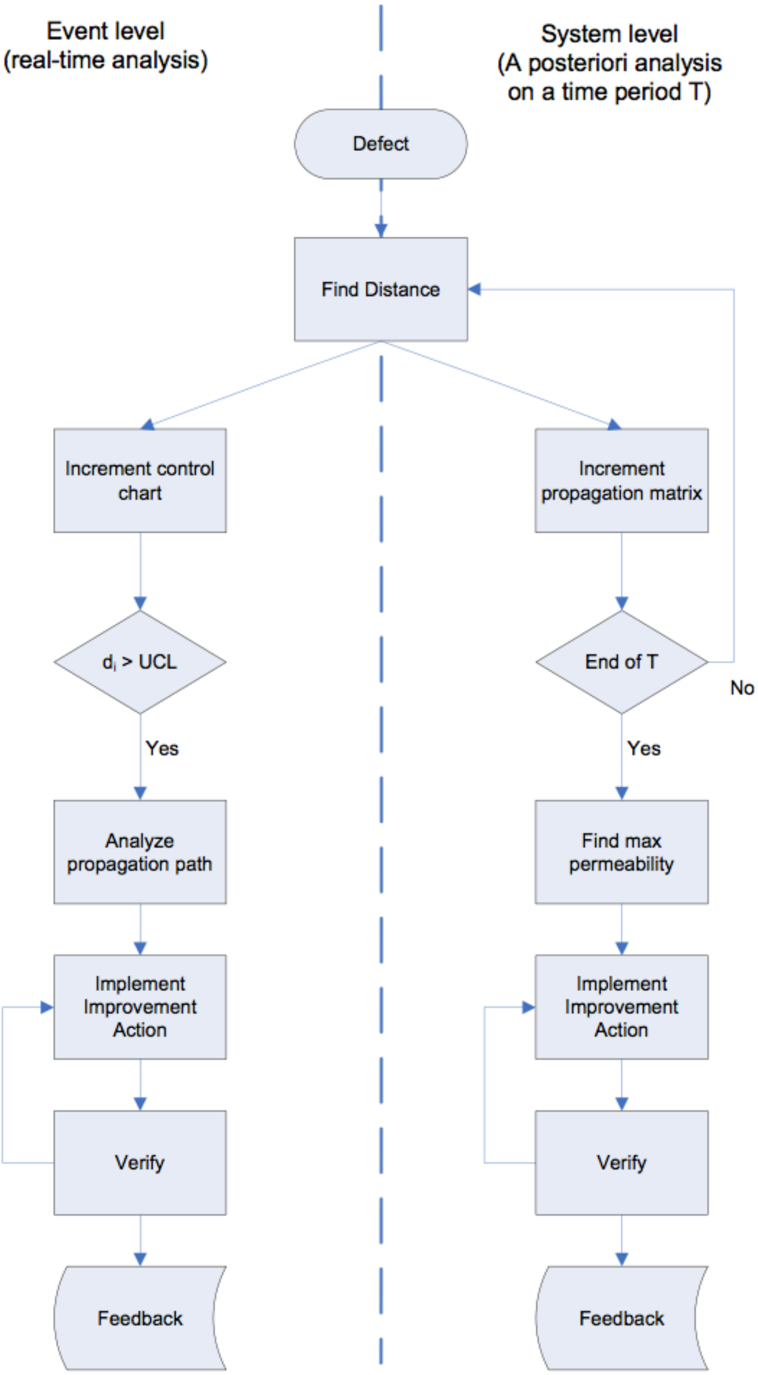


Figure 5-7: Method to use the model

This method ensures a continuous improvement over the process control system. In order to show the industrial applicability and utility of the method, two case studies have been issued and are presented in chapter 6.

5.1.3.5 *Evaluation of the method*

The proposed method can be evaluated on different basis. It has to be implemented in order to measure its relevance. Then three indicators can contribute to its evaluation:

- the propagation indicator itself has to be followed over several months. The correlation between actions from the system and the decrease of the propagation distance have to be studied
- the relevance of alarms triggered by the control chart have to be evaluated by the quality team
- Non-conformity costs: The goal of the method is to reduce propagation and thus non-conformity costs, particularly rework costs. The difficulty here is evaluating the contribution of the proposed method in the evolution of this indicator.

5.1.3.6 *Conclusion*

This section proposes two improvement tools to master propagation of non-conformities in manufacturing. First at the event level a propagation control chart is created and improvement actions are implemented as soon as a propagation threshold is overrun. Then at the system level, a propagation matrix inventories the defects over a given time period which highlights the permeability of the whole detection system. These decision-aid tools highlight weaknesses in the protection system and locate in the process improvement opportunities, to reinforce protection mechanisms. They are destined to the manufacturing quality department who will be in charge of their implementation and following. The industrial implementation of these tools will be described and discussed in chapter 6.

5.2 Which organizational design fosters resilience and transboundary problem-solving?

5.2.1 Objective

As explained in section 2, the analysis of the quality incidents shows that non-conformities propagate across the organizational boundaries. Seventy per cent of them are detected outside the department or operation they stem from. This reveals failures in the articulation of the different stages of the project delivery process, which is segmented into major, relatively partitioned, functional sectors. The realization of this type of failures induces a cross-functional problem-solving situation. It appears that these situations can be a good starting point for the improvement of coordination and communication. This section therefore contributes to thinking on transboundary risks, taking into account internal boundaries in an organization. The objective is to propose organizational mechanisms to ensure work continuity at the boundary between disjointed organizational universes during problem-solving situation and to better face risks and unforeseen events. This is summed up in the second research question and its sub-questions.

RQ 2: What kind of organizational dispositions foster resilience and transversality?

RQ2.1: In which measure can boundary spanners and boundary objects be pillars of the organizational resilience?
RQ2.2: Which methods and tools foster communication and collaboration between departments during problem-solving situation?

5.2.2 Approach taken

The research is based first of all on operational immersion in the company under study. Through 40 training sessions in Lean Manufacturing and running different workgroups on assembly errors and assembly documents, data concerning both quality problems and dysfunctions regarding articulations between departments are analyzed. This data collection was deepened through semi-directive interviews on the roles of different actors in the management of quality problems and interactions with other departments in crisis situations. Key actors from the different departments were questioned on problem solving mechanisms and crisis management (Technical, Design Office, industrial, logistics, production and quality) who occupy different levels in the hierarchy.

We also experienced a one-month total immersion on a production line (corresponding to our second exploratory study) to identify in detail all the barriers to control, redundancies and control breakdowns, which can lead to quality errors. The data collected within this framework comes from our own observations and interviews with assembly operators and team leaders.

In parallel, detailed analyses of fifty or so formal quality reports were performed, describing quality incidents, which had occurred in 2009 and 2010.

5.2.3 Boundary spanners: a reliable resilience pillar?

As described in section 5.1.2, around 50% of the controls performed by the operators on the assembly line are not formalized, and therefore relies on the competencies and vigilance of operators. During these controls, operators may detect non-conformities and correct them on their own. When they cannot manage the problem alone, they call their team leader. This is the case for most of the transboundary issues for which answers have to be found in other departments, like clarification of documents, non-conformities on parts, design problems, etc. The team leader will then act as a boundary spanner to retrieve information and solve the problem as explained in the following sub-section. Nevertheless, they can also become submerged by these boundary spanning activities, which can make them counterproductive (see section 5.2.3.2) and lead to some non-conformities not being rectified.

5.2.3.1 *Rearticulating work at the boundaries thanks to flexible and astute individuals*

In the case presented here, coordination breakdowns between departments have for a long time been compensated for by team leaders acting as boundary spanners who repair deviations, retrieve information and facilitate the circulation of information, drawings and objects to enable production continuity. They act as an interface between disjointed universes. It is they who detect a large number of errors and incoherencies. In this sense they are strong pillars of the organizational resilience.

Flexibility and “DIY” are presented in recent theories on risks as essential components of resilience. The case shows that the cleverness of the team leader, his ability to cross the boundaries to find information and to negotiate arrangements allow for the solving of many problems in the short term. Most of the daily degradations of the productive activity are corrected; the team leaders and their teams achieve the recovery of a relative order in the process and avoid most of the products’ accident that could occur. The team leaders gain power and a relative legitimacy for this and are considered as fire fighters vital to the productive process.

5.2.3.2 *Limit of an actor-based resilience*

Team leaders act with consistent involvement like fire fighters at the heart of the re-articulation work which is necessary to the process. However, the case also questions the limits of resiliency based only on the flexibility of those actors: when studied in accidental situations in particular, this flexibility may lead, in crisis cases linked to an accumulation of incidents, to the actors involved losing control. A disorganised environment that has too many “cognitive attractors ” wears actors down through a series of minor urgent tasks. This phenomenon is described by (Lahlou 2000) about intellectual workers (R&D). Boundary spanners are subjected to the same kind of cognitive overflows when trying to resolve transboundary unexpected disruptions. This is detailed in the following sub-section.

5.2.3.2.1 The boundary spanner is overrun with work which makes him less vigilant

In the case presented here, the team leader plays the role of boundary spanner. It is he who literally crosses interfaces to manage day-to-day problems in production. His role is that of a fire fighter who is in fact always reacting to emergency situations. He is extremely flexible and adaptable: he is a “DIY” specialist. The responsibility scope of the team leader is wide-ranging. He supervises an average team of twenty operators. This is four times more than recommended by Lean theories. Three team leaders cover the whole assembly of one product.

He is permanently solicited from all sides and is therefore completely overrun with work, which of course reduces his vigilance and increases his fatigue and stress. The multiplication of disruptions and the long response times from the support departments urge him to solve his problems alone, which maintains opacity over non-conformities and their management. He also has pressures in terms of deadlines because it is he who manages the production schedule of his workshop and is the guarantor of deadlines being respected. Thus, as described by (e Cunha, da Cunha, and Kamoche 1999), the management of unforeseen situations with severe time constraints can be a strong source of anxiety for those involved. The flexibility of those actors can lead to their becoming submerged. This situation also results in a general feeling of fatigue (Fiegenwald, Cholez, et al., 2011).

5.2.3.2.2 The boundary spanner has a bounded legitimacy

However, it is in their day-to-day management of unforeseen circumstances and improvisation that they find their legitimacy in their team. They have a certain power coming from their “undercover” problem solving capacities. But they are also acting alone because they lack legitimacy when facing the different support services. Indeed, their requests are often qualified by these latter as comfort modifications and refused.

The team leader acts mainly in emergency situations, coping with the daily failures of its workshop. Solving urgent problems does however remain primarily superficial because the team leader has neither the time to analyse the problems to find the deep root causes, nor the necessary legitimacy to put in place long term solutions to transboundary problems at an organizational level. As described by (PINA and CUNHA 2003) he can fall in an “opportunity trap” meaning that he does not manage to reuse knowledge acquired during the exploratory process of organizational improvisation. Analysis and implementation of long term actions is not his job, but that of quality experts. The boundary spanners do not have the legitimacy or the negotiating capacity to make their voices heard in terms of their perception of risks, and in particular when it comes to asking another department to reduce discrepancies relating to “risk-free” operations. The qualifier “comfort modification” by the designer of the modification requests from the production shows this different perception of risks and responsibilities, and the associated negotiated relationship.

5.2.3.2.3 The boundary spanner does not necessarily have the capacities to detect all deviations

The team leader does not have a global overview of the project and may sometimes underestimate the potential impacts of the problem on the organization, as well as the consequences of his isolated corrective action. Some of these corrective actions even lead to other problems. This was the case for example when a team leader decided on his own to extend an assembly practice that was put in place for a specific project by the industrial support, to other projects. This decision was made by the team leader because it simplified the assembly operation. However he was not aware that later in the process this modification would damage the material. Finally, the problem was detected on site, which caused costly reworks and undermined the image of the company to the final customer.

This situation shows that the team leader, like other actors, is pursuing a local optimum, the one of his team, which can be very different from the global optimum for the organization. He can only imagine failure scenarios according to past experience, which by definition is limited. His capacity to represent failure scenarios is limited. His capacities of anticipation are also limited.

The team leader may be confronted with problems whose solving requires not only DIY but also innovation. In that case they may lack technical expertise to make the necessary decisions. Moreover, transboundary problems can also appear on the shop floor at the boundaries between areas of responsibilities from different team leaders. The question of local optimum may also materialize there, for example in the management of WIP. The local optimum for each team leader is to produce the required quantities, but if the downstream process cannot absorb the produced quantities, it can lead to sub-assembly overload between the two areas, which can raise problems of safety and quality. This can be illustrated by the example of a team leader making his team work overtime, without telling the production supervisor, to respect the production planning, whereas the downstream team was blocked by a quality issue and thus not able to absorb the production. This team leader thought he was doing the right thing, because he was not aware of the current state of the downstream team.

Finally, the isolated management of dysfunctions prevents information on those problems from getting back to the appropriate departments. As a result, the dysfunction is very likely to reoccur. Thus, the team leader, who is an essential part of the organizational resilience, can also limit organizational learning.

5.2.3.3 *How to re-establish order and coherence in crisis management – use of third parties to ensure more stabilised coordination*

Flexibility is an essential component of crisis management. However, as above-mentioned, flexibility can also be counterproductive and does not allow sustainable problem solving. That means that minimal formalisation, as well as coherent and centralized articulation work are necessary.

Manufacturing Quality Assurance is well placed to play a role in the articulation work. The department has the position of an outside party with a global and objective view of the situation, as well as the required legitimacy to coordinate action. It organises the mediation of confrontational points of view, creates negotiation and arrangement platforms between actors through crisis meetings or workgroups and tables long-term solutions through the creation of transboundary objects such as the unforeseen situation management board. The success of these methods is due to the transversal approach coordinated and animated by a neutral actor, the Quality department. Through its third party position, the department has the legitimacy to bring all actors together in order to find solutions. Moreover it coordinates actions and follows their executions. Doing this, the department has really become a boundary spanner.

However, this was not always the position of the department, which was more oriented toward product and process control as well as system quality until 2008. It then evolved toward a transversal animation function, particularly with the development of a training team and a training centre and the implementation of problem solving methods. This shift was then amplified by the strong involvement of three members of the team in the Lean project in the field of quality culture and methodologies, competency management and training.

5.2.3.4 *Discussion*

We discuss here the limits of this type of resilience in the case of crises resulting from a succession of incidents, which occur over a long period of time. It would therefore appear that a minimum of formalisation is required, as well as coherent and unified articulation, which is recognised by all. Even though the definition of strict standards may not seem suitable, an action framework and legitimate coordination seem to be necessary to find long-term solutions to crises. As described by (Adrot and Garreau 2010), individual improvisation is not desirable in the management of transboundary crises. Organizational improvisation requires coordination between all actors involved.

This case also allows for examining the hypothesis which considers that the observation of the good recovery of the disruption, performed by the teams in daily activity, can predict the resilience of the organization. Here, an observation focused on the daily work of the production teams could reveal their relative resilience. But the study of the incidents suggests that this resilience is limited and can be a cause of disruptions and unawareness within the organization. Then, it shows the importance of having a scale of observation (temporally and organizationally) large enough to be able to identify some distinctions between local and transboundary resolutions, short term and long term learning.

When we study the scale of the interactions between the productive teams and the other departments of the organization, we meet some other limitations of the resilience of the existing system based on boundary spanners: limitations linked to their ability to run beyond the competitions between what can be named some organizational territories or organizational jurisdictions (Bechky 2003). Indeed, the notion of boundary evokes coordination problems and breakdowns in understanding that can occur inside and outside the organization. A negotiation exercise is therefore required to effectively accomplish collective activities. This articulation work is crucial, in particular during crisis periods. The question of who takes responsibility for it however is to do with issues linked to legitimacy.

The analysis of the overflow of the documentary process and of the team leaders reintroduces the issues of legitimacy as a condition of their effective action through boundaries (Strauss 1985). The literature has focused on the skills of communication of the boundary spanning individual who should speak several languages to facilitate the circulation of information across boundaries. In the case that we have presented, the team leaders also try to re-articulate the activities with many actions that can consist of a re-alignment of the tasks of the different departments involved. But if the emergency of the situation allows these temporary arrangements, it does not mean that the team-leaders are legitimate enough to be heard when they ask for permanent improvements linked to the infrastructure of the process (Star 2002; Star 1989). Comparing the responses of the team leaders and of the Manufacturing Quality Assurance, we suggest a new dimension of the boundary spanner’s activity, i.e. the creation of negotiation zones. This is done by the manufacturing quality team who initiates cross-functional meetings and working groups to trigger off confrontation of points of view and overrun local problem-solving. This also enables the finding of sustainable solutions.

5.2.4 Building boundary-spanning mechanisms to foster exchanges between departments and legitimate shop floor demands

As presented in the previous sub-section, boundary spanners are often and for different reasons doing local optimizations to solve their problems. This can be harmful in terms of sustainability, or can even be counterproductive. That's why an articulation work has to be performed at the boundary to ensure organizational resilience, particularly in problem-solving situations. But this articulation cannot only rely on individuals. For more reliability it has to be framed by formal mechanisms and to be institutionalized in the company. This sub-section presents five organizational dispositions, which contribute to the overall organizational resilience: the global lean spirit, training for production support departments, shop floor management, interdisciplinary working groups and efficient boundary objects.

5.2.4.1 *Lean spirit as a support for resilience*

The company started in 2009 a global Lean transformation. All departments were concerned, not only the production. Although controversies on lean manufacturing exist in the literature, and underline the potential negative impact of lean implementation on employees, we voluntarily choose not to enter this debate. Most of the failure in the implementation of lean manufacturing and most of the negative outcomes for employees arise from the way the implementation of the lean principles has been done. Like every principle it has to be implemented with due care and adapted to every specific company context. When used wisely, it can provide a real support for organizational resilience by rehabilitating the shop floor in the eyes of support departments, developing internal customer-supplier relationships, providing wiggling room for operators to participate in continuous improvement, fostering structured and cross-functional problem solving.

The literature on lean manufacturing presented in section 3 shows that one guiding principle in lean manufacturing is to refocus the attention of all departments on the shop floor, because it is at the shop floor level that value is created. This refocusing helps to legitimate the demands coming from the shop floor and to fight denigrating behaviours that have been observed for example when technical support qualified from "comfort modification" a demand from the production concerning the rectification of an incorrect drawing or when a technician was reluctant to go to the shop floor. The lean philosophy helps to overcome conventional perception of the shop floor (dangerous, dirty and stressful), which can discourage people to "go to gemba". Managers show the example and spend around 30% of their time there.

The lean philosophy also contributes to fostering internal customer-supplier relationship. Perceiving other departments as customer or suppliers adds a satisfaction dimension in the relationship. It encourages departments to further investigate the needs and satisfaction level of their internal customer and thus to improve themselves.

Lean messages were delivered in a simple and direct way to all employees by different channels. The project was launched during an annual meeting with all employees of the plant. The messages were then conveyed top-down by every level of management during monthly information meeting.

The success of developing a lean spirit in the company is due to different factors:

- *Dimension of the project*. It was a global company project, carrying the company vision. It has become a business motto for all employees
- *Management implication and support.* All top managers have conveyed relentlessly the lean messages and have been fully involved in the implementation, by carrying or taking part in one or more action plans.
- *Management exemplarity.* Managers have shown the example, by applying lean principles in their own work. They have for example done 5S in their own office, taken part in the shop floor meetings, elaborated their own standard working sheet, etc.
- *Assimilation by repetition*. Lean messages have been disseminated in a recurring and steady way by all possible channels. Direct communication to all employees has been privileged and done through annual, quarterly and monthly organization meetings in each department, and also during specific events like the lean evaluation for each department. Every occasion has been seized to repeat the messages and explain them carefully.

Lean messages have also been disseminated through a lean training campaign for all the employees. This will be detailed in the following sub-section.

5.2.4.2 *Training for the support services*

A lean training campaign for all employees has been launched in order to support the change project. The goal was to explicitly explain to people the transformation of the company, to share the objectives and the methods that will be used. The participants in the training sessions were voluntarily mixed, in order for people to get to know each other and foster interaction between departments.

The training (Fiegenwald, 2010a) is structured as follows. The first section was dedicated to the explanation of the lean project and its objectives. The point was to explain the strategy of the company and to detail the guiding principles, i.e. how the objectives will be achieved. The second section gives an overview of lean tools that were being implemented (5S, waste hunting, just-in-time, etc.). The third section illustrates through a lego game the basic principles of lean manufacturing (takt time, one-piece flow, autocontrol, supermarket, etc.). In the game, people were asked to build a production team composed of operators, quality experts, manager, technical experts and to produce backhoe loaders in lego to respond to a given customer demand (quantities and delivery time). One or two persons were asked to observe the situation and to report their commentaries at the end of each round. The initial situation of the game is given (team composition and production layout and rules). The game is then decomposed in four rounds between which improvements are undertaken by the team.

During this simulation exercise, participants were faced with non-conformities of differing nature (components, documents, assembly errors, material supply). These non-conformities sometimes went undetected and propagated until they reached the customer. They were similar to the ones people were confronted with on the shop floor. These disruptions put the team in a situation in which it had to cope with unexpected events, i.e. in which it has to be resilient. Various reactions to the degradations of the working conditions were observed. Particularly the search for responsibilities, and an increase of stress could be observed, as well as difficulty in finding a solution together. Faced with non-conformities, the team become completely disorganized and freaked out, what often worsens the situation and induces more non-conformities.

At the end of the round the team is asked to analyse what happened and to suggest improvement for the following round. They have to find mechanisms that will help them to reach their common goal, i.e. customer satisfaction (quality, quantity and delivery time). Among the suggestions of the participants, training of operators and of support departments is the very first to emerge. The first round of the game is actually launched without prior training for the operator, which leads to a lot of wasted time in understanding the assembly documents. Then, in 70% of the cases, an increase in resources is suggested. The team wants to hire more operators to satisfy the customer demand before thinking of the organizational changes that could improve the situation. Organizational inefficiencies, like the work organization on the line are not identified as potential error causes by the participant. As the number of operators are given, the team is encouraged to study production flows to find balancing issues. Once the question of the production flows and delivery quantities is solved, the team faces the quality issue of delivering defective products. It has then to find mechanisms to avoid mistake. When the team has reached a stable production state, a last disruption is created by increasing the quantities ordered by the customer. This is the final test for the team to assess its resilience. One dimension of this resilience relies on the production line architecture, which has to be industrially flexible enough to manage the increase. The second dimension is the team resilience, its ability to quickly adapt to the new situation. 90% of the teams passed the test and manage to respond to the customer's demand.

The evaluation of the training regarding its contribution to the organizational resilience is developed in section 6.2.

5.2.4.3 *Shop floor management*

As explained in the literature review and in the implementation of the lean philosophy in the company, one of the key principles is "go to gemba". This is true for the production managers but also for all the support teams (quality, industrial, technical, development, sales, purchase, etc.). This principle encourages cross-functional meetings directly on the shop floor, where the real value is added. Many cross-functional meetings were thus developed in the factory. Three examples are particularly relevant and detailed in Table 5-2: the midshift meeting in pre-fabrication, the production launch meeting, the reflex meeting at the entrance inspection. These meetings are all held on the shop floor with participants standing in front of a board. They have changed the interaction processes in place between the production and the support departments, who were often acting independently, without sharing information, and communicating through email. This induced lots of waste in terms of rework and waiting time. The meetings are very short (15 minutes) and happen weekly or even daily. The objectives are planning agreements and updates, problem solving or even anticipating potential difficulties in the case of the production launch meeting.

	Midshift pre-fabrication	Production launch meeting	Reflex entrance inspection
Objective	Order management, management of missing parts	Description of the project specifications to the operators	Problem solving concerning components
Launched	June 2011	June 2010	June 2010
Frequency	Daily	For every new project launched in production (approx. monthly)	Weekly
Duration	15 minutes	15 minutes	15 minutes
Participants	Warehouse, washing-painting, preparation, production, logistics, procurement	Project manager, operators	Entrance inspection, production, manufacturing quality, procurement

Table 5-2: Shop floor meetings

In addition to these formal meetings, a strong presence of the support department on the shop floor is helpful in detecting deviations as early as possible. The presence of the technical training team on the line proves highly effective in avoiding problems and detecting them after they occurred. Actually, these technical experts answer questions of operators during the course of their work.

A strong field presence is particularly relevant in the context of low-volume and high variability. In the case presented here, the company works in a project mode (Engineering-to-Order) what means great variability for the operators and more risks of errors.

5.2.4.4 *Interdisciplinary working groups*

Another mechanism to help foster cooperation is interdisciplinary working groups. This mechanism is used to solve complex issues implying different actors. The company has used these types of working groups since 2004 in the form of Kaizen working groups. The Kaizen approach consists in building an interdisciplinary team and applying it to a particular problem for one week. At the end of the week a solution has to be identified and its implementation has to have begun. It should be finalized within 60 days. These groups were animated by an external consultant. More than 50 Kaizen were conducted between 2004 and 2011. However, these events remain isolated and may lack coherence and continuity. Until 2009, they were the key asset in implementing lean actions at the company. From 2009 and the beginning of the lean project, they have become one tool among others in the lean tool box.

Other interdisciplinary working groups were launched and conducted internally, e.g. on tightening problems, on simplification of assembly documents, or on technical harmonization between the assembly methods of two products. These groups get together once a week for two to nine months. Each participant can be required to work on the subject between two team meetings. They always follow a structured problem solving methodology based on different steps: 1) Definition and clarification of the problem with the team 2) Search for the deep root causes 3) Search for solutions and classification of solutions 4) Action plan to implement the chosen solutions 5) Following of the action plan and verification of the efficiency of the implemented actions 6) Closure meeting and restitution to the top management. These groups are initiated, composed and animated by the manufacturing Quality team. This team has the neutrality, the legitimacy and the tools to take charge of the animation and the resulting action plan. These groups aim at finding long-term solutions to recurrent problems or to support major changes in the organization by provoking and structuring interactions between professionally disjointed universes, that would otherwise not coordinate, or have very less contact. This action by a third party ensures efficiency in the coordination. It helps to convey the idea of a common objective for all departments, which sometimes seem to be pursuing conflicting goals. It also helps in the debate to remain focused on the common objective.

Table 5-3 presents the characteristics of the different working groups animated or co-animated by the main researcher. The participants were always the production department and the support departments.

	Tightening	Documents	Relocation	Technical Harmonization
Objective	Eradicate the tightening problems (30% of the recorded assembly problems)	Eradicate the document problems (50% of the recorded assembly problems)	Risk analysis on the relocation of a production line in another production hall	Harmonization of assembly methods and documents between two products
Duration	Feb. 2010- Ap. 2010	Oct. 2010- Jan. 2011	Dec. 2010-Sept 2011	Fev. 2011-July 2011
Number of meetings	5	7	15	10
Participants	Operator, Team Leader, production manager, industrial support, technical support, quality expert, technical trainer	Operator, Team Leader, production manager, industrial support, technical support, primary engineering quality expert, technical trainer	Production manager, industrial support, technical support, quality expert, technical trainer	Operator, production manager, industrial support, technical support, quality expert, technical trainer
Researcher status	Animator	Animator	Co-animator	Co-animator

Table 5-3: Characteristics of the different working groups

The results and the evaluation of these working groups will be detailed in section 6.2.3.

5.2.5 Creation of efficient boundary objects

As explained in section 3, the concept of boundary objects has been developed by (Star and Griesemer, 1989) to analyse the nature of cooperative work in the absence of consensus.

This concept can be particularly useful in problem-solving situations, where actors have to coordinate around the common goal of finding a solution. In this situation, knowledge from different experts has to be shared and articulated, often in an innovative way. Collective improvisation is thus necessary. The stake is to frame the improvisation to generate fruitful interactions. Boundary objects in this situation can be a frame for action.

The literature gives characteristics of a boundary object, i.e. flexibility, shared languages for communication exchange, learning opportunity about differences, support a process of common knowledge transformation (Star and Griesemer, 1989; Bowker and Star, 2000; Carlile, 2002) but little evidence on why an object can fail to perform as a boundary object in a given situation. In the plant under study, many objects actually cross boundaries, like assembly documents, but these are clearly not boundary objects. They are non-flexible standards belonging to a particular department and thus fail to provide a *lingua franca* of exchange or to facilitate cooperation. On the contrary they can trigger errors at the assembly level because of lack of understanding and explanation.

In order to provide elements of an answer to this question, the transformation of a relevant boundary object in problem-solving situation has been studied. This object is a quality meeting called a 'Reflex meeting'. The goal of this meeting is to discuss quality issues encountered by the production team. Originally it was conducted weekly by the manufacturing quality in a meeting room. Participants were three quality experts of the manufacturing quality team, the production supervisors of the products (1 or 2 depending on the product), quality experts for the product (1 or 2), industrial support for the product, technical support for the product. This means up to 10 participants. It lasts one hour per product, and the meetings for the three products manufactured by the plant were conducted sequentially. This represented 3 hours of mobilization for the three quality experts of the manufacturing quality and up to 2 hours for other participants in case of flexibility on two products.

Problems were recorded in an excel sheet. The meeting proceeded as follows: all the opened problems in the excel sheet were reviewed to update their status. Then new problems of the week were discussed and recorded.

This meeting was one of the only to be cross-functional and dedicated to problem solving. Nevertheless, participants were not satisfied with the form of the meeting judged too long and inefficient because of the lack of ranking of the problems. Moreover conflicts often broke up between the different protagonists, who had difficulty finding a common satisfactory solution. Tensions were particularly strong between productivity objectives and quality objectives. Quality experts were perceived as playing the role of police, whereas production managers often acted under cover so as not to be stopped by the quality team. The manufacturing quality had difficulty playing its mediation role.

Even if the meeting was a good attempt to foster transboundary coordination, it was not very effective. That's why, after one year functioning, the quality team decided to transform it. Based on the guiding principles of lean manufacturing which were being implemented at that time, the quality team relocated its meeting directly to the shop floor. The excel sheet was closed and replaced by a white board. The meeting lasted 15 minutes, animated by a quality expert and people were standing in front of the board. The advantages of the board are:

- Its limited dimension. The amount of problems that can be registered on the board is limited (compared to the unlimited dimension of the excel sheet).
- Its high visibility. It is located directly on the shop floor. Every body can see the current problems, the actions undertaken and their status. This is in line with the transparency objectives of the lean approach.
- Its materiality. It is a shared material tool. It can be used outside the planned meeting to note problems. No need to lose time finding the shared file on the network.
- Its simplicity. No complex structure and only useful information. It is easy to read and to understand by all the involved actors.

The new form of the meeting also has many advantages. Its short duration and people standing help to keep focus on the problem. Moreover its location on the shop floor makes problems easier to understand for the participants. The problem can be shown directly to participants, which prevents misunderstanding in explanations. The board remains on the shop floor all week, which increases transparency in problem solving. Everybody can see current problems and their status. The limited amount of lines on the board makes it impossible to record new problems before solving old ones. As a result, the problem solving process makes gains in reactivity.

Table 5-4 summarizes the characteristics of the two forms of meeting.

	Form 1	**Form 2**
Frequency	Weekly	
Location	Sitting in a meeting room	Standing on the Shop floor
Duration	3 x 1 hour	2 x 15 minutes
Participants	Quality experts, production managers, industrial and technical experts	
Support	Excel sheet	White board
Opened problems	50	< 15
Time to solve problem	10 weeks	3 weeks
Strengths	Cross-functional Regular/ institutional	See form 1 + short + reactivity + transparency + adhesion
Weaknesses	Long Low reactivity Low adhesion of participants	Need for animation

Table 5-4: Comparison of the two forms of the reflex meeting

This analysis of the evolution of a boundary object enables one to draw actionable conclusions for practitioners who are trying to build or to evaluate these kinds of objects.

Even if a boundary object is linked to a particular situation, the study first shows that the object should have intrinsic characteristics, which can be seen as pre requisites for a boundary object. These characteristics are given below:

- Shared and available at any time for all the users.
- Wins the users' support. This support can be achieved in building the object with the users. This will ensure common understanding and representation as well as taking into account the multiple viewpoints. As recommended by (Carlile, 2002), it will establish a shared syntax or language for individuals.
- Simple to use and to update. Complex process will discourage the users in the long term. Use of the object should not be seen as a constraint for user.
- Standard enough to frame the actions
- Flexible enough to deal with the diversity of situations and to give people enough elbow room for developing new ideas
- Reliable. Information contained in the objects must be trustworthy.

In addition to these intrinsic characteristics, the boundary object has to live. The interaction around the object is of the highest importance in ensuring its efficiency. This interaction may not occur in a natural way. That's why it has to be structured and institutionalized. As described by (Sapsed and Salter, 2004) the lack of face to face interaction undermines the efficiency of the boundary object. A boundary object is not just an object that flows across boundaries (like technical drawings) or that lie on a given boundary. It should be a place where exchanges and negotiations occur. Finally, the best way to evaluate its efficiency is by looking at the level at which it achieves its primary goal, i.e. the improvement of coordination at a given boundary in a given situation. This measure depends on the context. In the case presented here a good indicator is the reactivity in problem solving. The evaluation of this boundary object will be detailed in section 6.2.4.

5.2.6 Conclusion

This section aimed at providing answers to our second research question:

RQ 2: What kind of organizational dispositions can foster resilience and transversality in problem-solving situations?

Different kinds of coordination mechanisms are analysed. First of all the use of boundary spanner to ensure work continuity at the boundaries is studied. The study reveals that these individuals who rectify a huge amount of problems are a core element of the organizational resilience in an environment disturbed by quality issues. However, relying only on these individuals is not viable. Boundary spanning activities can overwhelm these actors, who in turn can become counterproductive. More formal and reliable mechanisms are thus necessary. This section demonstrates the relevance of training and interdisciplinary working groups in bridging gaps between departments by aligning them toward a common objective. The last proposition developed in this section is to build efficient boundary objects. Based on the study of the evolution of a quality meeting, criteria for building a boundary object are proposed. The results of the implementation of all these coordination mechanisms in the companies under study as well as their evaluation will be presented in chapter 6.

CHAPTER 6 EXPERIMENTATION AND VALIDATION

This chapter details the implementation of the propagation tool and of the organizational mechanisms presented in chapter 5. This implementation has been tested in the company under study and extended to another industrial company operating in the high-volume and high-variability field. The last sub-section presents the evaluation of the research approach regarding the concept of validity and reliability presented in chapter 4.

6.1 Implementation of the propagation tool

The implementation of the tool is done in three steps. First, a retrospective study is conducted with historical data on quality problems over a year. Then a three-month real time analysis is performed. Finally, the tool has been implemented and automated in a second company to validate its relevance in another industrial context.

6.1.1 Retrospective study

This first study aimed at validating the applicability of the proposed method and tool before starting an implementation in the factory. The two levels of the strategy proposed in chapter 5 (system and event) are implemented simultaneously.

6.1.1.1 *Data collection and analysis*

The analysis is based on previous non-conformity reports for one product of the company, issued over one year between 2009-2010 from different sources like factory and installation quality reports, quality meetings, and quality campaign for the operators. This analysis showed that quality defects detected during assembly are coming either from the design phase, or from raw materials, or from assembly mistakes in the same proportion. As explained in chapter 5, we deliberately chose not to consider defects coming from the design stage. The remaining defect amount is 41. For each defect, the analysis of the formal report has been completed and clarified by interviews of the quality teams and production managers. The goal was to identify for each non-conformity the generation step and the detection step. The process has been split into 15 operations to fit to the successive assembly steps.

6.1.1.2 *System analysis*

The 41 defects have been recorded in a 15x15 matrix presented in Table 6-1, corresponding to the 15 process steps. The matrix gives the number of defect occurrences for each (generation; detection) couple. The average propagation distance for these defects is 6 operations. That means that a defect will on average, run through 6 different process steps before being detected. In the case presented here, it represents 40% of the process length. The average permeability of the process operations is 43%, i.e. each process steps let 43% of the defects pass through. This permeability indicator does not take into account the rectified errors that are not formally recorded, i.e. it should be seen as a relative. These two indicators are macroscopic indicators for the performance of the global protection system and particularly for the detection speed and efficiency in the low-volume field where classical ARL and ATS are not relevant.

The totals for each row and column give an overview of the worst defect generators and the best defect detectors. This matrix allows three rankings of the process operations, according to their generation propensity, detection ability and permeability.

- The worst defect generators are then: OP1, OP5 and OP8

For instance, the total 15 for the first row shows that the first operation is the worst non-conformities generator in the process. The analysis of the first line also shows that 7 out of these 15 defects have been detected only at the last process step, meaning a maximal propagation. Improvement efforts on these steps should be directed toward 1) auto-control or double-checking, 2) training for the operators 3) fool-proofing when possible on parts or with assembly kits.

- The best defect detectors are: OP15, OP10, OP11

These process steps are located in the last third of the process, what confirms that detection is done very late in the process. The total of 13 for the last column reveals that the last process step is actually the best non-conformity detector.

- The most permeable process steps are: OP8, OP9, OP10

These successive process steps are located right in the middle of the process. This highlights an improvement opportunity of the detection system. Effort should particularly be focused on the OP8, which is both highly permeable and a defect generator. The analysis of the type of defects that are not detected here could feed a control checklist for this operation, as well as training for operators in order to increase their vigilance on the most frequent types of defects they do not see.

Detection location

Generation location	OP 1	OP 2	OP 3	OP 4	OP 5	OP 6	OP 7	OP 8	OP 9	OP 10	OP 11	OP 12	OP 13	OP 14	OP 15	Generated
OP 1				4	1			1		1	1				7	15
OP 2					1											1
OP 3																0
OP 4								1								1
OP 5					1			1		6	4				1	13
OP 6																0
OP 7															1	1
OP 8										4		1				5
OP 9																0
OP 10														1		1
OP 11																0
OP 12																0
OP 13															4	4
OP 14																0
OP 15																0
Detected	0	0	0	4	3	0	0	3	0	11	5	1	0	1	13	**41**
Permeability (%)	37	39	39	27	56	56	59	63	63	39	27	24	34	32	0	**43**

Table 6-1: Propagation matrix

6.1.1.3 *Event level analysis*

The analysis enabled to draw the following control charts of the propagation distance and the associated moving range (Figure 6-1). Each point on the distance control chart represents the propagation distance of one defect.

The classical statistical limits for individual and moving range charts (Montgomery, 2007) do not lead to any detection and are unsatisfactory in our industrial context (low volumes, high customization, and long lead times). Actually UCL_D is close to the number of process steps (15), meaning that the detection system lets nonconformities propagate along the whole process, leading to huge costs for the firm. This is not acceptable that's why the limits should be revised downward. They are set at UCL' = N/2 (half of the total process steps) as proposed in chapter 5 when UCL is close to N.

Alarm examples with these new limits are encircled in Figure 6-1. Data show that the UCL' defined at N/2 would have triggered seven alarms and so many improvement actions of the control system. Even if UCL' is not statistically based from an alpha-risk point of view, events remain manageable. These eight alarms would have been manageable for a process control team either to decide to postpone action or to perform process control improvement actions. In this case, there is no false detection, as all alarms triggered actions that are necessary to decrease the propagation distance, when the objective is to tend toward null propagation.

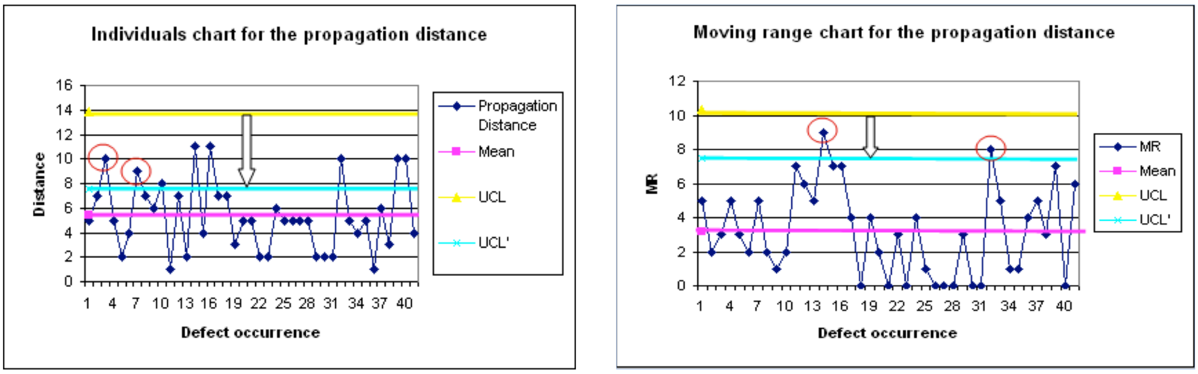
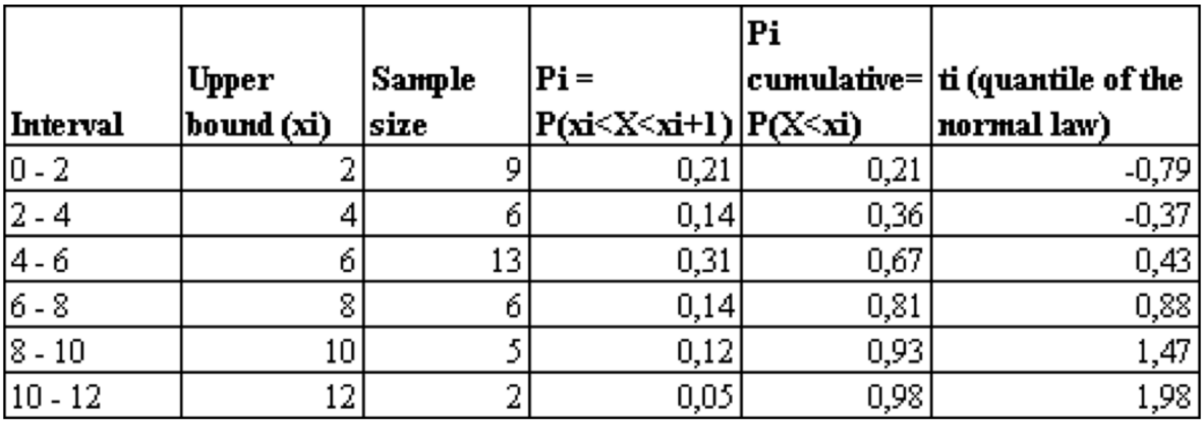


Figure 6-1: Individuals and Moving Range charts for the propagation distance

The analysis of the distance distribution with a Q-Q plot method shows that we can assume that the propagation distance is close to a normal distribution.

Given the limited amount of data (41 distance records) on the interval [0;12], this interval has been split in 6 classes:]0;2],] 2 ;4], etc .

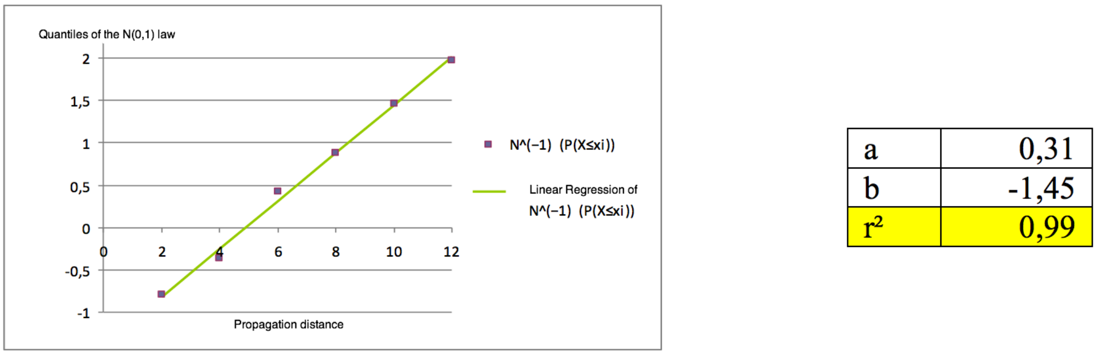
The quantiles of the normal distribution (ti) are calculated for each value of the cumulative distribution function at the upper bound of the previous interval (P(X<xi)). The values for the (ti) are represented in Table 6-2.



Interval	Upper bound (xi)	Sample size	Pi = P(xi<X<xi+1)	Pi cumulative= P(X<xi)	ti (quantile of the normal law)
0 - 2	2	9	0,21	0,21	-0,79
2 - 4	4	6	0,14	0,36	-0,37
4 - 6	6	13	0,31	0,67	0,43
6 - 8	8	6	0,14	0,81	0,88
8 - 10	10	5	0,12	0,93	1,47
10 - 12	12	2	0,05	0,98	1,98

Table 6-2: Quantiles of the normal law

A linear regression is then applied to these values and validates their alignment. The r^2 coefficient close to "1" confirms this hypothesis. Data containing forty-one measures is actually enough to run a normality test but is quite low to obtain an accurate approximation.



a	0,31
b	-1,45
r^2	0,99

Figure 6-2: Q-Q Plot and regression coefficients

This analysis has been presented to the steering committee on September 30th 2010 (Fiegenwald, 2010b). It was decided to

- Renew the study in real-time settings during three months in order to validate that actions are manageable on real-time basis and to see the evolution of the propagation indicator.
- Conduct a global auto-control campaign. This has been implemented through technical training and lean training and through the addition of an auto-control operation and an associated allocated time on every standard working sheet.
- Conduct actions on the OP8. The content of the operation and of the associated controls have been reviewed and training has been deepened for operators on this process step.
- Conduct actions on defects coming from OP1, particularly vigilance for every following operation.

The results of these actions will be discussed in the following sub-section after the real-time analysis and will show how they contributed[3] to the decrease of the propagation and how the presented tool enables to measure it.

6.1.2 Real-time study

Six months after the *a posteriori* case study, the control chart has been implemented for a three months real time test period following the decision of the steering committee.

6.1.2.1 *Data collection and analysis*

Data on non-conformities were collected during three months from April to July 2011 from quality reports concerning two products. After the first analysis, the production lines for two products have been merged in a flexible line. Operators and operations are the same for the two products, that's why we choose to consider both of them, what induces an increase in quantity of available data. The control chart (event level) was completed for every single data. The matrix (system level) was then implemented with the data of the three months and compared to the previous analysis.

6.1.2.2 *Event level analysis*

Defects were recorded and improvement actions were taken as soon as the propagation threshold was overrun.

As shown is the first case study, the standard limit calculation is unsatisfactory because it is much too high in comparison with the physical number of assembly steps N. The upper control limit was then set at 7,5 (N/2) and decreased from one unit after five defects without alarm.

This system triggered 4 alarms on the individual chart and 2 more on the MR chart during the period as shown in Figure 6-3. Variations show that the detection process is not stable. Analysis of these alarms and the associated actions is given below. Once again, it was more important to get alarms for potential drift throughout the manufacturing system, than to have a statistically correct UCL. The 6 alarms are detailed below.

- Alarm 1: This alarm highlighted a well-known and recurrent assembly mistake. It concerns the wrong orientation of a part on a subassembly assembled at operation 8. This part is at the exterior of the material and is thus visible until the end of the process. Nevertheless, no formal control is performed on this particular point until operation 13. This mistake is easy to correct even at a late

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[3] These actions were part of a global quality initiative.

stage in the assembly process that is why not much effort has been deployed to avoid it or to prevent its propagation.

- Alarm 2: This alarm pointed out an incoming material degradation due to an error in the washing process that led to the oxidation of the component. This defect has propagated through the whole assembly process and was detected by chance (there was no formal control requesting this verification) at the last control before shipping. Although it was visible, this defect propagated through 10 assembly steps including 3 formal controls. It was the first time this problem was encountered. This explains the lack of formal verification and also the lack of vigilance of the operators. Nevertheless this very visible problem questions the ability of operators to have a global view of the assembly and of the quality requirements. Oxidation problems are actually well known problems for different parts. In spite of this knowledge, operators were not able to interpret their observation and generalize to the current situation. This alarm induces a large amount of verification for materials that have been assembled in the meantime. That disrupted the normal process flow and induced production delay.

- Alarm 3: The same defect as for alarm 2, assembled before detection of the first occurrence of the defect. The distance is yet the same as for the previous defect, but the additional temporary control put in place following the previous alarm, protected the company from a potential external propagation and enabled it to stop 3 more occurrences what would have induced serious products recalls from customers.

- Alarm 4: Warn an assembly mistake concerning a lack of tightening. This defect propagated from 6 steps until the final inspection (operation 13). This tightening is verified by auto-control at the operation. This tightening is not verified later in the process. This first questions the efficiency of auto-control, especially in the context of long assembly times for a given operation. In this case the sustaining of vigilance can be difficult. This vigilance is guided by following sheets but this may not be enough, given the complexity of the assembly. Moreover, attention of operators on this particular assembly step has been driven toward other verifications on highly critical points for the safety and the functioning of the material and for which problems have been encountered in the past. This focus may divert the operators from other verifications.

- Alarm 5: It was judged irrelevant by the quality team.

- Alarm 6: This alarms points out the assembly of a wrong part reference in the factory that has been detected during an on-site installation, i.e. the last process step before the final customer. The alarm showed that no control on this point was performed in the factory, whereas the problem only become visible during the on site assembly when it became blocking. Without a formal control, this error related to the length of the component cannot be seen in the factory.

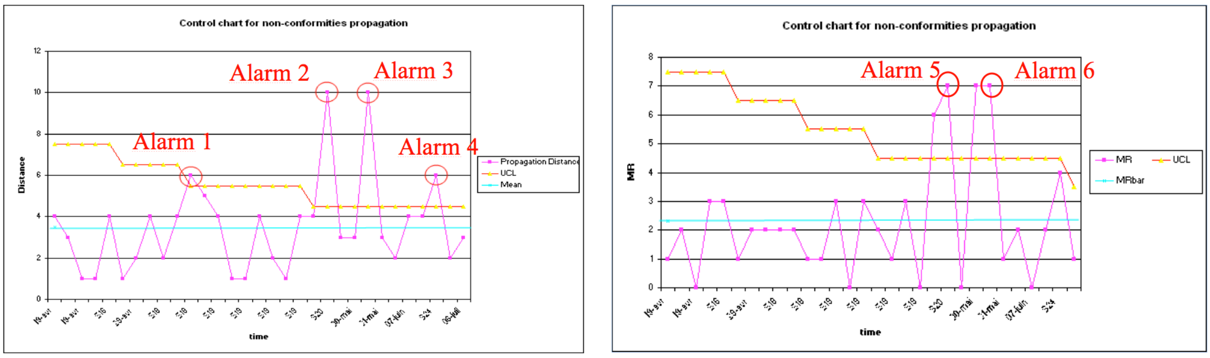


Figure 6-3: Individuals and Moving Range charts for the propagation distance over a three-month period

This real-time implementation of the method showed that it is adapted to the detection of weaknesses in the control system. Alarms actually pointed out lack of control or porous control. The quantity of alarm is manageable, and irrelevant ones are easily sorted out. The definition of UCL = N/2 and its decrease every five defect without alarm shows that UCL can be reduced very quickly.

This implementation was conducted by the manufacturing quality team who collected the data and followed the control chart. Each alarm was discussed with quality experts and production managers in order to decide what actions should be launched.

The stake in these decisions was to secure the protection system without complicating it too much by additional controls. Reluctance in adding formal control has been observed particularly in the production side, for example following alarm 6, because of the fear of complicating already complex control processes. Moreover, in a lean perspective, controls are seen as non-value added operations. A consensus has nevertheless been reached on a temporary additional verification following alarm 2 settled at the last process step in order to avoid external propagation.

Moreover, a systematic action put in place after the alarms is a root cause analysis conducted by the manufacturing quality team. Some of the root causes were then handled by working groups.

Actions put in place following the alarms are essentially awareness campaigns, training or temporary additional verification. Even though no deep modification of the detection system has been undertaken, alarms highlighted severe weaknesses and contribute to increase vigilance of the management and of the operators.

Nevertheless the time period was too short to observe a real improvement in the distance. Another implementation period starting with these values should be set up to observe an improvement in the propagation distance.

6.1.2.3 *System level analysis*

This analysis was conducted with data recorded over a period T = 3 months. Twenty-five defects were recorded in the propagation matrix Table 6-3. The average propagation distance over these three months is 3,5 process steps, i.e. 40% lower as in the previous study. The average permeability indicator is 31%, i.e. 12% lower as in the previous study. It means that the situation has globally improved. Particularly, data on detection show that no problem seems to have reached the end of the process, when more than a third of the recorded problems in the first study were detected at the last process step. A positive evolution is also observable at the first process step. This operation is still the worst defect generator but with 24% of the defects, when it was responsible for 36% of them in the first study. Moreover, these defects have been detected earlier in the process, as they propagated in average from 6,5 steps, when they propagated from 9,3 steps in the first study. Another positive evolution has impacted operation 8, whose permeability decreased from 43%.

This global improvement is due to all the quality initiatives in the plant including actions taken after the first study to improve the protection system.

Even if the situation improved, data from these 3 months also highlight that half of the recorded defects have been detected at operation 13, i.e late in the process.

The analysis also emphasized that operations 5 and 6 are highly porous. Effort should be directed here because problems on sub-assemblies realized during these operations may not be detected before operation 12. Moreover efforts have to be maintained on operation 8 because it is approximately in the middle of the assembly process, and because it is a step, which offers great detection opportunities (detectability). All defects that propagated through this step should actually have been stopped here. It would mean for these 11 defects a detection 3,8 steps sooner and an improvement opportunity of the global distance mean of 39%.

Detection location

Generation location

	OP 1	OP 2	OP 3	OP 4	OP 5	OP 6	OP 7	OP 8	OP 9	OP 10	OP 11	OP 12	OP 13	OP 14	OP 15	Gene-rated
OP 1						1	3	1		1						6
OP 2																0
OP 3													1			1
OP 4																0
OP 5							2	1	1							4
OP 6																0
OP 7								1					1			2
OP 8									1				4			5
OP 9													3			3
OP 10																0
OP 11													3			3
OP 12													1			1
OP 13																0
OP 14																0
OP 15																0
Detected	0	0	0	0	0	1	5	3	2	1	0	0	13	0	0	**25**
Permeability (%)	24	24	28	28	44	40	28	36	40	36	48	52	0	0	0	**31**

Table 6-3: Propagation matrix from April to July 2011

6.1.3 Test in another industrial context

After the two previous studies in the low-volume and high-variability context, it was decided to generalize the findings in another industrial context, high-volume and high-variability.

6.1.3.1 *Profile of the case company*

This case study was conducted in a manufacturing factory building instrumentation for process industries. The production line under study manufactures pressure transmitters for industrial applications. These devices are highly customizable but manufactured in high volumes (140 000 per year). The challenge for the company is to handle this high number of variants in a Lean manner. It put in place three years ago a U-cell assembly line and autonomous teams for this product. The assembly consists in manual sequential operations followed by tests and configuration. The number of steps in the assembly process ranges between 27 and 32. Auto control is requested for each assembly step. Products are tracked along the whole process and non-conformities are recorded by the operators in the ERP. When an operator detects a defect during the assembly, he is to eject the product from the line. It is then taken in charge by a repairman. The line employs two full time repairmen for 15 operators. Around 7% of the products assembled by the line undergo reparation. This impacts the quality and productivity indicators.

6.1.3.2 *Data collection and analysis*

Thanks to its ERP the company has complete records of its quality problems. For each defect the cause of the problem is filled in the system by the repairman, thanks to an error catalogue. Around 300 defects were recorded each month. The analysis was conducted over a three-month period. Data was completed by direct field observations and interviews of operators, quality technicians, and production managers.

6.1.3.3 *Implementation of the tools*

Regarding the amount of data to be analysed, an automation of the tools is required.
The starting point is the error database extracted from the ERP. Information needed in order to calculate the propagation distance is:

- Detection location: provided by the error database through a detection code
- Generation location: not provided in the database
- Assembly plan in order to calculate the length of the propagation path: available in an excel file

The stake is thus to find the generation location for each defect with the available data. This was a difficulty identified by (Fiegenwald, Bassetto, et al., 2011) which has been removed here thanks to an error catalogue which lists all known potential errors and which is used by the repairman to fill in the error cause in a standard way for each product repaired. The analysis of this error catalogue makes it possible to assign without ambiguity a generation location to 80% of the error codes. This has been done by adding a field in the error catalogue. Thanks to this association, 85% of the recorded errors could be affected a generation location.

An automation of the calculation could then be performed thanks to a VBA program. The data model is given in **Erreur ! Source du renvoi introuvable.**. The left side of the igure presents the structure of the error database before implementation of the tool. The right side shows the classes that have been added to compute the method. Three attributes have been added to the error class: generation step, detection step and propagation distance. These attributes are calculated thanks to the error codes and the assembly plans. The permeability class has been created in order to assess for each process step the level of defect generation, detection and permeability over a given period. These attributes are calculated thank to the error data and the assembly plans. The instruction to use the automated propagation tool is given in Appendix VIII.

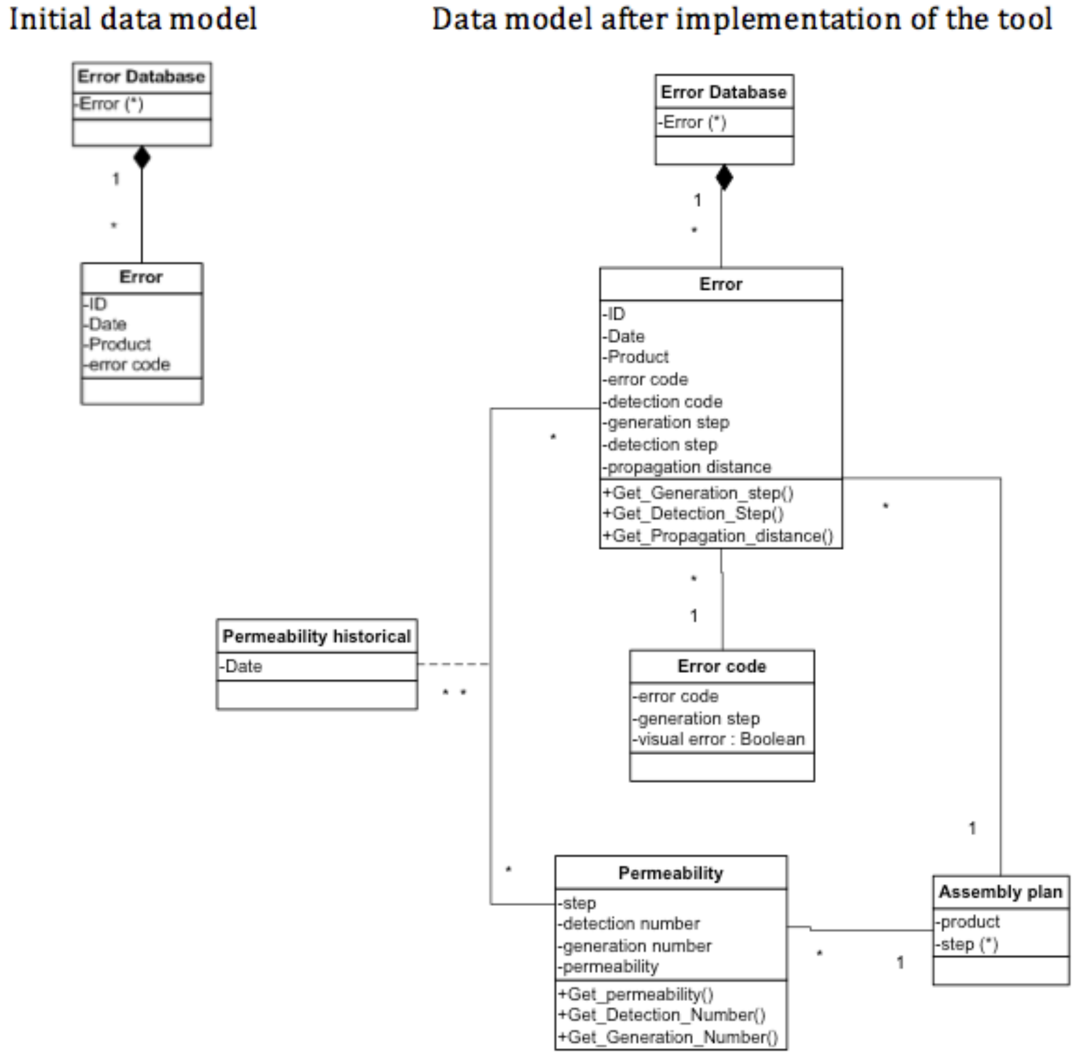


Figure 6-4: Data model

6.1.3.3.1 Event level: Propagation Alarm

The first tool gives an overview of the defects over a given timeframe. For each defect in the database, the program finds the generation and detection steps as explained above. Then it calculates the propagation distance given the product and its assembly plan.

It is possible to set a propagation threshold to consider only the worst propagation case, or to consider only visual defects. This tool can be used daily or weekly for a real time analysis and quick response to deviations. It can also be used on a longer time period, like the month in order to evaluate the average propagation, and classify defects regarding their propagation. Table 6-4 shows the structure of the output.

Defect ID	Product	Serial number	Date	Description	Generation step	Detection step	Propagation Distance	Visual
20037201	A	N1BD2134	01/10/2011	Text 1	OP 5	OP 10	5	Yes
20037202	B	N1BD2140	01/10/2011	Text 2	OP 1	OP 3	2	No
20037203	C	N1BD2156	01/10/2011	Text 3	OP15	OP 30	15	Yes

Table 6-4: Propagation distance

6.1.3.3.2 System level: Permeability analysis

The second analysis level gives for each process steps the number of defects generated, detected and the number of missed detection (permeability) over a given timeframe. This tool can be used on a monthly or quarterly basis, in order to identify the most porous process steps. It shows the weaknesses in the detection system and highlights were efforts can be made in order to improve the detection process.

Data can be visualized on the graph in Figure 6-5, which crosses the three dimensions. Process steps are presented in the assembly order, except for OP12', 13' and 14' which only concern particular product variants. For each operation, the figure shows the cumulative defect generation, detection and permeability (missed detections). For example, in December 2011, OP21 has generated 16 defects, detected 75 defects and missed the detection of 97 defects. The analysis of these curves is given in the following sub-section.

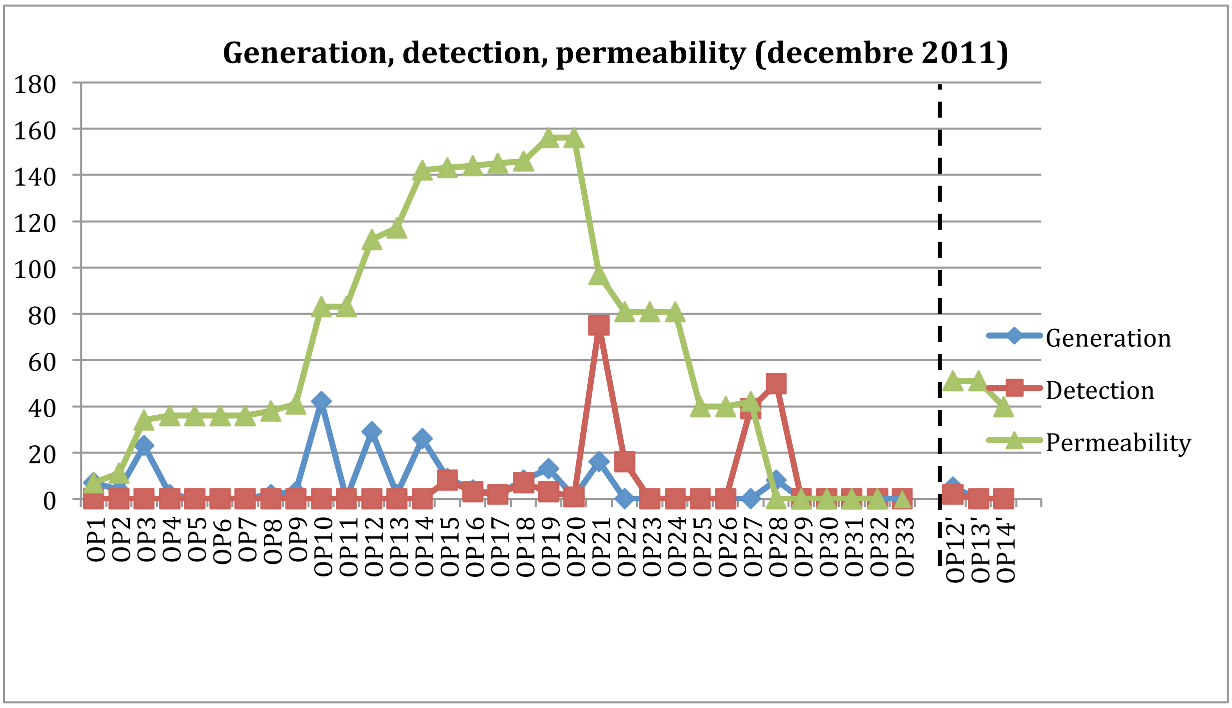


Figure 6-5: Generation, detection, permeability (december 2011)

6.1.3.4 *Findings*

The analysis performed on a three-month period gives insights into the worst defect generators, the better detectors and the more permeable process steps. It shows that:

- The average propagation distance is 11 process steps (for an assembly process including 30 steps). This average distance is approximately the same whether only visual defects or all defects are considered.
- The better detectors are the same for the three months. These four steps correspond to the formal controls on the line (OP21, OP22, OP27, OP28). Moreover, the first of these four controls appears very lately in the process (position 21/33 in the assembly plan). Other process steps detect very few defects, even though auto-control is requested for each step and a third of the defects are visually detectable.
- The permeability analysis shows that, even if OP21 is the best defect detector, it also generates defects and is one of the most permeable steps. This step corresponds to electrical tests which filter electrical problems, but not visual defects. The most permeable step is the whole U-cell (from OP13 to OP20). These 8 steps do not detect any problem even though auto-control is required. This highlights the weakness of the auto-control process. This is also visible on the permeability curve Figure 3. The permeability of the steps in the U-cell (from OP13 to OP20) is the highest in the process.
- The step OP12 is both a defect generator and a highly permeable step. This step corresponds to the part launch in the U-Cell. It consists in picking parts to assemble, regarding the customer demand, generating a serial number for the device and launching the parts in the line.
- Finally, another permeability peak can be seen on Figure 3 for the steps OP12', 13' and 14'. These steps are external of the line and concern 20% of the products assembled on the line. They refer to a customization of the device which requires some parts to be removed and others to be added.

The analysis of the weaknesses in the detection system conducted with the proposed tools leads to the following recommendation for the company.

- Efforts have to be directed toward the step OP12. This step is well positioned in the process to be a good defect filter. Actually, all visual defects coming from the upstream steps could be stopped at this place. This would avoid adding value to already defective devices. It could be done, by specifying specific control points for the operator before launching the parts. These control points could be displayed on photos on the operator's workstation. The data of the 3 months under study show that the detection potential had been 27% of all defects and 44% of the visual defects.

- Efforts could also be put on the step OP12', whose complexity has been under evaluated. Many assembly errors are generated here. It is a complex operation, which is not standard. During the study we observed that operators performing this task were not always trained properly. Recommendation for this step is to consolidate the operator training and to reinforce the visual management on the workstation, like for the step OP12, by displaying visual control points.
- A particular attention should be given to the U-Cell, which is globally highly permeable. This U-cell is composed of assembly operations without formal control stations. This questions the definition of auto-control in this part of the line, as well as the knowledge of the operators about the quality requirements. Moreover, organizational factors for the lack of vigilance have to be studied, especially the team autonomy, the work organization and the cooperation between operators. This will be detailed in the second part of this chapter.
- Observation on the line also showed a great variability in the control methods between operators. The lack of standard makes it difficult for operators to identify deviations from the quality requirements.

The propagation analysis could be used by the quality team as a communication tool with the operators on major defects in order to raise their awareness on auto-control and vigilance.

6.1.4 Discussion

The proposed method aims at following and reducing the non-conformities propagation distance in the manufacturing systems from order to delivery. We assume that this indicator gives a macroscopic view of the performance of the global protection system. In contrast to classical control charts, it focuses on defects from all types and originating from different sources. This method identifies the depth with which non-conformities cross protection barriers (propagation indicator) and also the size of the breaches of these barriers (permeability indicator). The proposed tools are decision aid tools, which do not tell *what* actions to undertake, but which highlight *where* efforts have to be directed at in order to improve the performance of the whole detection system. They do not exempt quality teams from analysing defect root causes, nor from being present on the shop floor.

The analysis conducted in the case study shows that the tools are industrially relevant. They can be used by the quality as a decision-aid tool to direct improvement effort. A general two-step method (short timeframe and long timeframe) for the use of the presented tools in other industries is given below. Analysis frequency for each part of the method has to be adjusted regarding production volumes. A PDCA method is applied in each case in order to define, implement and verify actions to reduce the propagation.

1. Short time frame: Propagation analysis - PDCA on the threshold overrun
2. Long timeframe: Permeability analysis- PDCA on the permeability

The proposed method presents several industrial interests. First it gives the company a macroscopic performance indicator of its protection system. Then, even if major defects can be detected and corrected besides the system, and if rectified defects are not taken into account, it is of great interest to detect drifts in the protection system because of the high costs linked to propagation and to rectifications.

This simple tool is easy to use for managers and will point out weaknesses in the protection system and improvement opportunities. The method will help managers to focus their quality and improvement efforts, giving orientation for the quality and continuous improvement working groups.

According to the two first studies, the control of the propagation distance and the implementation of the associated improvement actions in case of alarm seem to be profitable. Following the evolution of the distance can be a decision making tool for implementation of improvement actions. In the three studies, quality tools and working groups are generally implemented for major defects only: this qualification is however quite arbitrary, based on the perception of potential impacts more than on frequency. The presented tool could thus be a more realistic trigger to start improvement action. The industrial application of the method already proved operational utility in triggering such actions. Finally, data from the tool could be used to update risk analyses, like FMEA. The automation of the method presented in the third study shows that the tools can be implemented with reasonable efforts when data are available. The availability of data can actually be problem. The propagation distance indicator is based on the assumption that generation and detection locations of defects can be identified. Even if detection location is easily known, the identification of the generation location can sometimes be more complicated, if not impossible. However, finding the generation location has been made possible in the third study thanks to an association with the existing error codes for 80% of them. The remaining 20% have deliberately not been considered because of the impossibility to find a generation location. It took one day and two persons to initiate the process by doing the matching between the 250 error codes and the detection steps, which is a relative low effort. An update procedure for the error catalogue has to be defined in order to take into account new types of defects.

The proposed model however presents some limits. First, the propagation and permeability are relative, because they are calculated on recorded defects and do not take into account rectified defects on which no information is available. Then, it requires available data on quality issues that can be complicated if not impossible to find. This quality data is more likely to be retrieved in companies with mature quality systems. However, empirical case studies show that it is possible to focus only on defects for which information is available. In the third study this information was available in 80% of the cases, which is satisfying given the amount of defect (more than 300 per month). It is enough to draw a picture of the protection system. Secondly, the distance indicator calculated in process steps unit does not take into account the detection possibility for each process step. Actually, each defect cannot be detected at each process step. The detection may require particular equipment, or the defect may be hidden from a particular point in the assembly.

But the distance calculated with process steps already containing formal detection of the defect would make loose the improvement opportunity. Finally the distance calculation does not take into account the position of the generation and detection location in the process. A weighting could be implemented in order to take into account higher risks of external propagation when generation and detection come closer to the end of the process.

The case of the Alarm 3 in the second study, pointing out the same defect as alarm 2 shows the impact of the improvement action implementation delays combined with long production lead times on the material at risk. Production should actually be stopped in case of alarm to limit the propagation of other potential defects of the same nature. This recommendation is, however, very unlikely to be accepted by the management due to induced shortfall.

The three months observation window in the second study is not long enough to observe the recurrence of a specific defect. The time period is too short to evaluate the performance of improvement actions undertaken to enhance the detection system. A research avenue could be to test in laboratory a simulated production system and to introduce defects in order to evaluate the impact of the action on the propagation.

The detection of deviations relies on humans. It means that the ATS is not mastered. In order to refine the model, the detection speed and the type I and type II errors have to be investigated. Ideally this indicator should be included in the information system as well as the results of the improvement actions.

6.2 Implementation of the organizational dispositions

This section presents the results of the implementation of organizational dispositions to foster resilience in problem solving situations. The different propositions presented in chapter 5 will be discussed and evaluated. Data collected at Siemens E T HS MFG were completed by direct observations and interviews at Siemens I A SC MFH.

6.2.1 Lean training

As explained in section 5.2.4, certain aspects of the lean philosophy can support the organizational resilience. In the first company under study, lean trainings have been a key vector in the dissemination and implementation of lean principles. Thus, this section proposes an evaluation of these training as well as an analysis of their contribution in different dimensions of the organizational resilience, i.e. the rehabilitation of the shop floor, the understanding of the production constraints, the cross-functional exchanges around problems, the understanding of the delivery process articulation, and the impact of non-conformities that propagate internally and externally.

The evaluation of the lean training was performed in two-steps. First, a satisfaction questionnaire was proposed to the participants at the end of the training. The results of this survey show that the employees, globally, were very satisfied with the training as they gave the training an average rate of 3,3/4. They have particularly appreciated the clarity of the message and the lego-game. No significant differences have been observed in the evaluation of the different departments.

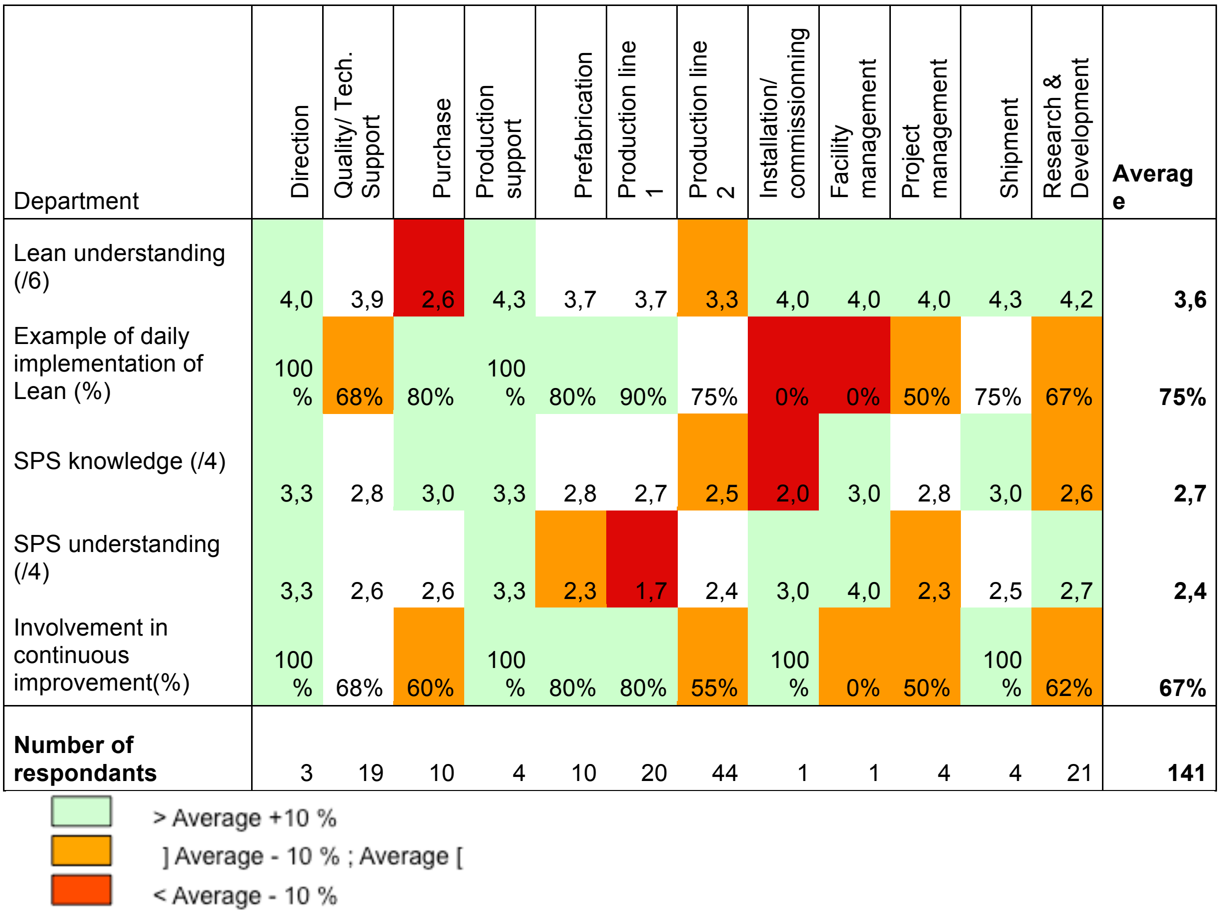
Then, a before/after training questionnaire was performed in order to evaluate the level of lean knowledge before and just after the training. This method allows evaluating the comprehension of the fundamental concepts of lean manufacturing. As it was performed immediately after the training, a second evaluation is necessary to evaluate the assimilation of the concepts in the long-term. This evaluation was performed by means of an anonymous questionnaire 3 months after the training. As the training sessions took place from February to September 2010, data was collected on a rolling horizon between Mai 2010 and December 2010. The questionnaires were disseminated through a web-based application and through paper for operators. These hand-written answers were registered in the application in order to facilitate the analysis. Table 6-5 shows the evolution of the comprehension of lean concepts before and after the training. A major improvement in the understanding of lean and SPS concepts is observable after the training. The understanding of the lean philosophy seems to be sustainable, since 86% of people are able to explain the key principles 3 months after the training. Concerning the SPS understanding, a decrease is noticed between the post-training evaluation and the evaluation performed three months later. This may be due to the abstract dimension of the SPS, especially for operators. Nevertheless, 61% of people are still able to explain the SPS core principles three months after the training. Involvement in continuous improvement globally improved from 10%. Two-third of the employees are involved in a continuous improvement action. This is to be linked with the generalization of lean in the factory during the year. At the end of the training 79% of people think that lean principles could be implemented in their department and give an example of possible benefits. Three months after the training, 75% of people declare that they have an example of lean actions in their department.

These results show that the lean project has reached within one year the global scale it intended to reach.

	Before training	**After training**	**3 months after training**
Understanding of lean concepts	40%	88 %	86%
Understanding of SPS	26%	87%	61%
Involvement in continuous improvement	56%		67%
Lean applicability	NA	79%	75%

Table 6-5: Understanding of lean concepts before and after the training

In order to go deeper in the analysis, results by departments are presented in Table 6-6. The survey first confirms the commitment of the board to the lean project (see first column). It shows that the Lean philosophy is globally well understood by people. The department MFG2 (Purchase) presents the lowest score in this category. 75% of people see examples of lean implementation in their daily work. A difference is clearly visible between production and support departments. Actually, the lowest scores are observed for support services: MFG1 (Quality and Technical Support), MFG7 (installation and commissioning), MFG Facility Management, MFG PM (Project management), and TIGD (Research & Development). Globally, people have an understanding that lean is a company project and are able to explain the guiding principles. Finally, 67% of people are participating to a continuous improvement action. Once again a difference is visible between production and support department. This is explained by the fact that during the first project year, improvement efforts were driven toward production. Moreover, the lean project has been presented to the employees as a tool for shop floor enhancement, what may have been understood by support departments as a devaluation of their own work. A lean administration action plan will start in the beginning of the second project year.



Department	Direction	Quality/ Tech. Support	Purchase	Production support	Prefabrication	Production line 1	Production line 2	Installation/ commissionning	Facility management	Project management	Shipment	Research & Development	**Average**
Lean understanding (/6)	4,0	3,9	2,6	4,3	3,7	3,7	3,3	4,0	4,0	4,0	4,3	4,2	**3,6**
Example of daily implementation of Lean (%)	100 %	68%	80%	100 %	80%	90%	75%	0%	0%	50%	75%	67%	**75%**
SPS knowledge (/4)	3,3	2,8	3,0	3,3	2,8	2,7	2,5	2,0	3,0	2,8	3,0	2,6	**2,7**
SPS understanding (/4)	3,3	2,6	2,6	3,3	2,3	1,7	2,4	3,0	4,0	2,3	2,5	2,7	**2,4**
Involvement in continuous improvement(%)	100 %	68%	60%	100 %	80%	80%	55%	100 %	0%	50%	100 %	62%	**67%**
Number of respondants	3	19	10	4	10	20	44	1	1	4	4	21	**141**

🟩 > Average +10 %
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🟥 < Average - 10 %

Table 6-6: Lean maturity evaluation 3 months after the training (data collected on a sample of 141 people)

The understanding of the lean philosophy and how it is implemented in the factory is also visible in the responses to the open question asked in the questionnaire: *What does Lean in our factory mean to you?* Among the answer of non-managers some are really interesting in showing the commitment and trust of people in the project.

- The objective of a global quality always improving

Common sense, simply, neatly.

- A working philosophy
- A corporate culture in a continuous improvement spirit
- A line of action to define and follow together
- The satisfaction of the customer while improving our everyday work
- To constantly reassess oneself
- A corporate vision
- The way forward
- Quality every day. The desire to do well. The hope to be heard and understood.

Besides the benefits in terms of dissemination of the lean philosophy, the lean training provided significant contributions to the improvement of resilience and transboundary problem solving.

6.2.1.1 *Rehabilitation of the shop floor*

One of the core messages of the training is that the factory is pursuing a vision of operational excellence that relies on all the employees. The first goal of the training is to share this vision and associated guiding principles and to exchange with employees on it. This vision is centred on the shop floor, where the real-value is created. The responsibility of support departments is to make the production flow. That is their top-priority. Plant indicators defined in accordance with this vision are OTD (on time delivery), NCC (non-conformity costs) and production Lead-time.

This vision contributes to the "rehabilitation" of shop floor, which was devalued by support department members. An explanation of this devaluation is that employees in the support departments often stem from the production and see their production leaving as an upward social mobility. They cannot imagine going back to production, as shown by a technician at the design office who was surprised to get an invitation for the lean training in which people were asked to come with their safety shoes because a part of the training was performed directly on the shop floor.

> *"You must be mistaken, I am not concerned about this training, you wrote in the invitation that we have to take our safety shoes." Engineer at the design office*

This state of mind also contributes feeding the division between departments. That's why one of the goal of the training was to bring people on the shop floor to make them understand their role in the global delivery process and how their work (documents, methods, etc.) is used on the shop floor. They understood that if the production does not flow, their upstream work is vain and loose its sense.

6.2.1.2 *Understanding of the production constraints*

The lego game enabled comprehension of the production constraints by the support departments. Particularly the concept of Takt Time (rhythm of the customer demand) was unknown by the support departments. There is an understanding that the production line is meant to deliver one product per day to the customer. That implies that a breakdown in production has to be corrected in the hour to maintain this rhythm. This concept was a revelation for the technical support department, which is in charge of solving technical problems in production. Production is sometimes stopped until the technical support comes to the shop floor and decides what to do. This waiting time could reach several days and represents a shortfall for the production, which complains about the technical support not being reactive enough. On the technical support side, the reactivity was judged good enough, given the amount of other tasks these engineers and technicians have to cope with. The request of the production was judged irrational.

Understanding the production rhythm made the need of reactivity clear for the technical support whom initiate a reorganization of the tasks and dedicate one technician to the production support with clear reactivity objectives.

> *"We were not aware of the impact of our intervention delays on the production flow. We have plenty of other problems to deal with. Problems in production were not the top priority."*
> *Technician in the technical support department during a lean training*

6.2.1.3 ***Training as an exchange time***

The training sessions were organized so as to have mixed-teams of people coming from different departments. This was done to make people meet and to foster exchanges. As the training includes time to speak about problems, the different department can learn about the problems of the others and can sometimes provide explanations. The trades of every department are clarified, what contributes to the increase of the global knowledge of the organization. It was observed that people speak a lot together during these training, and creates bond between them. It also contributes to people knowing each other and building their internal expert network. In case of a problem they know whom they can contact. It would be interesting to study on the long term how these networks can be activated in case of problems and how this could increase reactivity.

6.2.1.4 ***Comprehension of the process articulation particularly for operators and team leaders***

Articulation of the whole production process is not easy to understand for production workers, whose knowledge is often limited to their team area. The lego game proposed in the training enables an elevation on the flow level. This made the operators and team leaders aware of the problem of WIP (work in progress) between process operations. In real life, each production team has its own delivery objectives. Sub-assemblies are thus pushed in WIP areas between operations without considering the need of the following operation. This behaviour can induce huge WIP in case of problem at one step.

The training made the people aware of these interfaces and the necessary management of them. There is no need to produce if the following step is not able to absorb the produced quantities.

6.2.1.5 ***Understanding of the complexity of the assembly documents***

The lego game includes an assembly document to support the operators in their tasks. This document is the same as the standard working sheet found on the shop floor. It summarizes the major process steps, provides illustrations and highlights key points for each step. An example is given in appendix.

After the first round of the game, 50% of the assembled pieces presented non-conformities, particularly an orientation problem of one part assembled at the first process step. This part could be assembled with two different orientations and an orientation mistake was not a blocking for the following process steps. The standard working sheet highlights this particular vigilance point but after the first round, 90% of the participants at this workstation concealed not having read the vigilance point. The proportion is the same for all employees, whether they are production operators, or support departments. This questions the effectiveness of this kind of textual warning and show that very little attention is given to the written procedures. Operators in the game were asked to deal with only one type of document, when real operators have to juggle with at least 5 different documents to realize their assembly. The error opportunity is then very high. This is confirmed by the analysis of quality reports (provided in chapter 2), which demonstrates that half of the assembly mistakes are due to documents (misunderstanding, update, etc.). A major issue with documents that was highlighted by the game is that assembly documents are not designed in a customer-oriented perspective. Support departments often forget that the final users of their documents are the production operators, and do not ask themselves which kind of information is relevant for the operators. Instead they stick to complicated standards, which overflow operators with information that are for the major part of them irrelevant for the assembly. Moreover, this information overflow dilutes the relevant information, what increases the risk of not seeing it. This really encourages simplification of the assembly documentation. An interdisciplinary working group has been launched on this topic. Results are discussed in section 6.2.3.

6.2.1.6 *Impact of the NC that propagates in terms of flow disruption*

During the game, participants were confronted with different kind of non-conformities, similar to those encountered in real production (parts non-conformities, assembly mistakes, preparation mistakes, errors on documents, etc.). These disruptions generate rework that has to be taken in charge by the line. This rework disrupts the process flow and induces an overload of work for the operators, who have to deal with their normal work at the same time in order to respect the planned delivery time. The game confronted the participants with the management of such disruptions and made them understand the dispositions taken in such cases to manage the overload as well as the stress that can be felt on the operators' side. They experienced that in such situations errors can easily be committed, and can even more easily propagate because of a relaxing of controls or a decrease in vigilance. The game thus highlights the necessity of implementation of particular dispositions for the management of rework.

6.2.2 Shopfloor management

Chapter 5 presented different cross-functional shop floor meetings that have been implemented in order to foster exchanges between departments, particularly in problem-solving situations in order to avoid propagation. The evaluation of the contribution of these measures to transboundary problem solving is given below.

6.2.2.1 *Evaluation of the Midshift meeting in the preassembly line*

This meeting has been introduced as part of a lean project aiming at reducing the lead time of the pre-assembly line and improving its service rate. It is conducted daily in the preassembly line with participants of the procurement, logistic, warehouse, painting, preparation of parts and production. The goal is to share a visual overview of the production planning and progress of the production orders as well as the status of missing parts.

The benefits of this meeting are the following:

- Reactivity

The daily rhythm of the meeting allows a high reactivity in problem solving and in information exchange. The presence of all actors enables immediate decision taking and avoids long decision process.

- Reliability in the delivery process

The meeting board is a reliable and available source of information for all participants, even besides the meeting. This information sharing increases reliability in the delivery process by validating process times and anticipating problems. This also enables the pre-assembly line to deliver the production orders with an OTD (On Time Delivery) of 83% (compared to 66% before the project) and an average of 0,21 missing parts, when it was 0,46 before implementation of the meeting.

- Lead time

The lead time of the whole pre-assembly process has been decreased from 10 to 6 days thanks to a value stream analysis and implementation of the meeting.

6.2.2.2 *Evaluation of the production launch meeting*

This meeting has been launched in order to share information on project specifications between project manager and production operators. It is conducted by the project manager before the beginning of each new project (every month or every two months depending on the production rhythm and the project size). The benefits are the following:

- Sharing of information on project specificities

The company working in project mode, each project has its own specificities, which have to be taken into account in the production. Many problems previously occur because of a lack of communication or explanation of these specificities to the operators. This communication aims at increasing the vigilance of operators on specificities they could have missed when only reading the assembly documents.

- Shop floor at the centre of the concerns

On the side of the project manager, it enables a refocusing on the production, as it requires an information processing effort to translate the specifications in the production language and make sure they are understood. This contributes to fostering the internal customer-supplier relationship between production and project management.

- Contextualization of work

On the operator side, these meetings enable a contextualization of their work. They will actually learn more about the final customer, the history of the company with this customer, the specificifications linked to the country of the customer, etc. This understanding contributes to giving sense to the work of the operators, to their motivation and to the alignment toward the common goal of delivering a specific product on time to the final customer.

6.2.2.3 *Reflex entrance inspection*

This meeting concerns the non-conformities of parts coming from the supplier. These non-conformities can be detected at the entrance inspection but also in production. All problems and their status are displayed on a board in front of which procurement, quality controllers and production meet every week. This enables:

- Transparency on the problems

Information on problems and corrective actions are available at any time for every department.

- Reactivity

As for the midshift meeting in the preassembly line, the presence of all actors enables quick information exchanges and decision taking.

6.2.2.4 *Reorganization of the technical support department*

In order to face the increasing demand of reactivity and the increasing amount of solicitations linked to the implementation of lean manufacturing, the technical support department has decided to reorganize its activities and to dedicate two of its members to full time production support for the three products. The other mission of the department is to ensure the technical management of the products across their lifecycle. It is responsible for all the modification of parts or assembly methods that may occur during the product lifecycle. It also participates in the qualification of the suppliers with the purchase department. Before this reorganization, all the employees in the department could be solicited on problems occurring in production. The teams were organized by products and then have people dedicated to sub-assemblies in one product. The new organization implied the development of flexibility for the both technicians between products and between assemblies. These two persons are also dedicated to the different cross-functional shop floor meetings and working groups. This new organization clearly increased the reactivity of the department, which now react to production disruption within 2 hours.

6.2.3 Interdisciplinary working groups

As presented in chapter 5, interdisciplinary working groups are used to foster transboundary problem solving. Four working groups are presented in Table 6-7. Major changes were achieved through these groups, for example the standardization of the torque-tightening unit in all documents (three different units were used at that time). Long-term successful actions have also resulted like the concept of thematic quality weeks, which aims at focusing on a particular quality topic during a week through a visual communication campaign, specific audits on the workstations and an animation in the shop floor for all operators. This concept has encountered great success (Fiegenwald, 2012).

Among these working groups, the group on documents did not fully reach the original goal of eradication of the assembly problems due to documents (understanding, accuracy, updating). One of the root causes of documentary issues is the complexity and the multiplicity of assembly documents. These documents are issued by the different support services, and can be redundant or even contradictory. They are also issued at different points in time during the product life cycle, what compromises overall coherence. Furthermore, document updating is not handled effectively by the organization because of the diversity of modification channels. Attempts at simplifying assembly documents have for the moment proved unproductive. Each department is convinced of the usefulness of the documents it issues and is not prepared to discuss. The perspective of the internal customer (assembly operators) is on this particular point difficult to understand by the support departments, which remain stuck in the corporate standards and norms. No consensus could be reached toward a unique assembly document for the operator. The tendency actually seems to be the creation of even more documents (kit list, safety data sheet, etc.).

Nevertheless, the technical harmonization group conducted to support the relocation of a production line enabled to make a step toward the simplification of documents. The goal of this working group was to ensure coherence between technical drawings and assembly procedures for two similar products that will share the same production line and operators, when they have been designed by two different teams at different time and assembled by two different teams in two different production halls.

The problem was to support and secure the flexibility of workers by harmonizing assembly methods for equivalent sub-assemblies (sub-assembly decomposition, Gluing, tightening, greasing, tests, etc.).

This goal was reached by systematic comparison of drawings and procedures. Two technical experts and one industrial expert have been dedicated to this mission for three months. Seventy drawings were modified as well as 40 assembly procedures. A change in the mind-sets of these support departments has been observed during this period. They were actually reluctant to take part in this project given the induced amount of time that would be required to do all the modifications and the lack of understanding of the relevance of the project. However, after a few meetings with expert operators directly on the shop floor, they understood the complexity of the assembly and the potential risks of errors due to falsely similar designs and procedures. Management support and dedication of technical experts to this project also contributed to its success.

	Tightening	Documents	Relocation	Technical Harmonization
Objective	Eradicate the tightening problems (30% of the recorded assembly problems)	Eradicate the document problems (50% of the recorded assembly problems)	Risk analysis on the relocation of a production in another production hall	Harmonization of assembly methods and documents between two products
Duration	Feb. 2010- Ap. 2010	Oct. 2010- Jan. 2011	Dec. 2010-Sept 2011	Fev. 2011-July 2011
Number of meeting	5	7	15	10
Participants	Operator, Team Leader, production manager, industrial support, technical support, quality expert, technical trainer	Operator, Team Leader, production manager, industrial support, technical support, primary engineering quality expert, technical trainer	Production manager, industrial support, technical support, quality expert, technical trainer	Operator, production manager, industrial support, technical support, quality expert, technical trainer
Researcher status	Animator	Animator	Co-animator	Co-animator

Results	Standardization of the unit of tightening torque Tool reallocation on the work stations Communication flyer	No simplification achieved, Standardization of the picking lists for kit preparation	2 week training for the operator Colour coding (documents, parts, tools, work stations, etc.) to distinguish between products Technical harmonization	70 Drawing modifications 40 assembly procedure modifications 10 diffusion meeting on the shop floor
Following action plan	Audits	Questionnaire on the management practices of team leader and production manager Quality thematic weeks	Daily shop floor presence of the quality, industrial and technical teams during 3 weeks following the relocation	Audits, memo sheets on the differences between products
REX	No technical solution found, Unit standardization was crucial Many “soft” solutions proposed (training, organization, etc.)	No simplification achieved because of the “property” of documents No alignment achieved toward the need of the end-customer(operators)	Good preparation before moving, good collaboration between industrial, production and quality teams Closing meeting sept. 2011	Heavy work load, Dedication of an industrial and a technical expert, Should have begun earlier

Table 6-7: Interdisciplinary working groups

6.2.4 Boundary objects

As explained in chapter 5, the concept of boundary object is particularly useful to ensure coordination and work continuity at boundaries between departments, particularly in problem-solving situations. Nevertheless, certain objects thought to be boundary objects like assembly documents (drawings, procedures, etc.) fail to perform in this way.

This section aims at proposing an analysis of two types of objects thought to be boundary objects but which do not fully succeed in performing as such: the assembly documents and the quality board on the shop floor.

6.2.4.1 *Assembly documents*

The case of the assembly documents shows that these documents issued by the different support departments (technical support, design office, industrial support, quality, safety, etc.) do not perform as boundary objects because of their multiplicity. The attempt to simplify these documents through a cross-functional working group has failed. The different departments did not manage to create a unique document, which makes sense for all, and especially for the production, which is the user of the documents. The reasons for this failing will be detailed in section 6.2.6.

6.2.4.2 *Quality board*

The quality board that has been set up on the shop floor serves to support problem solving. The board has different functions in the problem solving process.

1. Identify and record the problems: the creation of a new line on the board during the meeting implies that participants agreed on the qualification of the problem (everybody agrees that it is a problem) and on its description. This requires people to negotiate and agree.
2. Make the problems publicly known: everybody can see the problems, the operators, the support departments and even customers that visit the factory.
3. Remember on-going problems: the board is a reference to remind actors of problems to be solved. No other record exists for these problems. The quality team accepted to abandon the traceability provided by the previous method (excel file) in order to gain in visibility and reactivity.
4. Incorporate problem-solving methodology: the structure of the board is simple but ensure that problems are always defined in the same way, and that persons in charge of the action, the deadline and the status are known. It also incorporates on its back a problem solving methodology in case of major problems (crisis). The board is then moved onto the problem location and serves as support for the understanding of the problem and its root causes as well as for the corrective actions to be put in place.

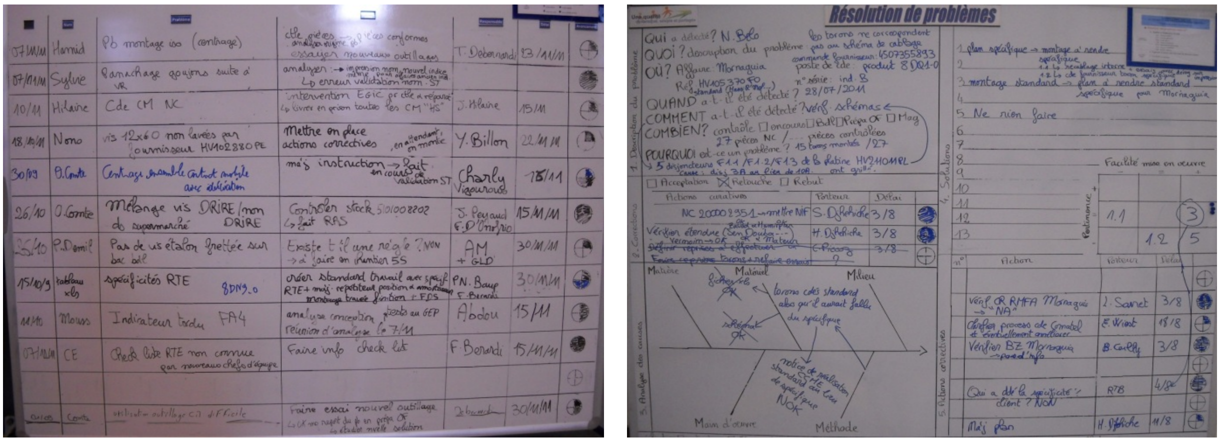


Figure 6-6: Quality boards

Figure 6-6displays the two sides of the board: the support for the quality meetings and the support for the solving of major problems.

The board plays a role of partial boundary object. On the one hand, people appropriate the board and use it outside of the meeting. It is actually the reference for information on on-going problems. People go to the board to get information on on-going problems and their status. The board also plays a role of a reminder, for the production supervisor for example, who writes down his problems besides the formal quality meeting just to remind himself to talk about them during the meeting. The board has become a boundary object because it provides a space for exchange and coordination between departments around a common objective, the continuity of the production flow. As described by (Star et Griesemer 1989), it has become a location where intersecting worlds create representations together. This common representation satisfies potentially conflicting sets of concerns.

But on the other hand, the efficiency of the board partly relies on its animation. It has been observed that despite its institutional dimension, the need for animation remains. The object is not sufficient unto itself. Without animator, it will not take place. A situation where the animator was absent has been observed: people as every week came to the board at the time for the meeting, wait five minutes for the animator and then on mutual agreement decide to go back to their offices. No one takes over for the animator. People did not even read the board.

The findings about the quality board in the first company have been confronted to a similar board, called "continuous improvement board" in the second factory around which institutionalized cross-functional meetings have been observed. These boards are composed of production indicators, problems, information for the team, competence matrix, and improvement suggestions as shown in Figure 6-7.

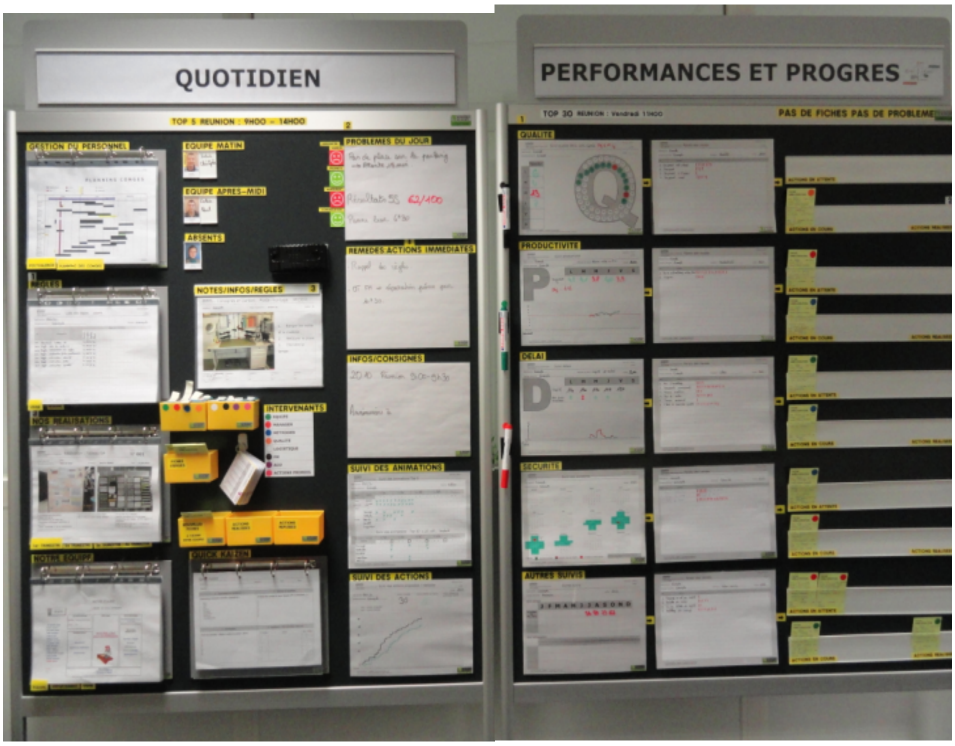


Figure 6-7: Continuous improvement board

In this company, the production relies on autonomous working teams with turning animators. Each production cell has its own “continuous improvement” board around which two meetings are conducted. The first meeting is a five-minute daily meeting conducted by the production animator with the operators aiming at sharing the problems of the previous day as well as on information exchange between the morning and afternoon teams.

The exchanges are very limited, with the animator only presenting the productivity indicator of the previous day. Very little comments are given on the operator side. This can be partly explained by the lack of legitimacy of the animator, which is a production operator of the team, who lacks hierarchical power and is not properly trained to take on this function. Moreover, its belonging to the team can prevent him from being objective and playing the arbitration and mediation part of its role. Operators are not interested in the board, which is too complex and displays too much information.

The second meeting is a weekly thirty-minute meeting conducted in front of the same board but animated by the production manager. Participants are support departments (quality, industrial support) and animators of the team. Production indicators of the week are reviewed, as well as the major problems. Finally new suggestions of improvement actions are reviewed and one opened action is reviewed. The problem with this meeting is that it addresses very different topics in a very short time. Moreover, the production manager is overloaded because he can be responsible for up to ten teams, which means ten similar meetings every week. The same problem is encountered by the other support departments, who are also responsible for the entire assembly process.

Finally, people doubt the utility of these boards and meetings, which have been put in place by the continuous improvement team. They are seen as too complicated and have been implemented in a top-down manner without enough consultation. Some managers do not even want to launch this approach in their workshop judging it inefficient and time consuming.

To sum up, the analysis of these meetings and associated board shows that they lack some of the intrinsic characteristics of boundary objects presented in chapter 5. First, their top-down implementation has incited rejection from the users. Then, information displayed on the board is too complex, and does not represent a shared language for the different department. They have been implemented as a standard in the whole factory, on different workshops and even different products without taking their specificities into account. This confrontation of experiences contributes to answering the question of why an object will work as a boundary object or not. This will be detailed in the following sub-section.

6.2.5 Discussion

This sub-section aims at discussing three concepts presented in this section regarding their contribution to the organizational resilience, i.e. the lego-game, the work or rearticulation and the use of boundary objects.

6.2.5.1 *Contribution of the lego-game*

The contribution of serious game in the learning process has been widely analysed in the literature (Sterman and Off, 1992; Badurdeen et al., 2009; Faria et al., 2009). In the example presented here, the game enabled participants to simulate a production flow and associated problems and therefore put them in a situation similar to ones encountered in the factory. This simulation first aimed at making people understand lean concepts of takt time, line balancing, auto-control. But the game also aimed at making employees of support departments aware of the production and its constraints. This contributed to the rehabilitation of the shop floor and of its demands. The game illustrated phenomena such as the generation of non-conformities and their management in a mastered environment with limited stakes. It also contributes to illustrate the problem of assembly document understanding.

Even if people were mainly able to draw the parallel between the game and the real situation, some differences were noted. First, the short assembly times in the game were very different from the long assembly times encountered in the real assembly. The short times in the game induced a stress for the “operators” that was not foreseen and that may be a bias in the analysis. Some people felt really pressured by these times and could not manage to do their work. The focus on the respect of the delivery time was more intense in the game than in the real life.

6.2.5.2 *Work of rearticulation*

In the course of normal activity such as when facing unforeseen events, organizational breakdowns always need to be reduced. According to (Strauss, 1988), alignment is always necessary to ensure business continuity and what Strauss calls the work of articulation, which must accommodate the different actors whilst the action is underway. Articulation requires negotiations and arrangements. Actors will align their definitions of the situation, or at least make them compatible around a shared objective. This articulation work can be the responsibility of individuals (boundary spanners) or objects (boundary objects) which allow meaning and language to be shared, along with the alignment of practices, learning and people’s understanding of the roles of other actors.

All the approaches presented in this section contribute to the rearticulating of tasks and to making sense of the positioning of tasks from one to the next. They give a collective and organizational sense for operators and support departments. They contribute to providing a human dimension to the organization and to the good will of people, particularly in problem solving. However, this willingness does not mean that people have the means to solve their problems. This has been demonstrated with the analysis of the boundary spanning activity of the team leader. These approaches also contributed to creating interfaces, materialized in objects or location.

When we study the scale of the interactions between the productive teams and the other departments of the organization, we meet some other limitations of the resilience of the existing system based on boundary spanners individuals: limitations linked to their ability to run beyond the competitions between what can be named some organizational territories or organizational jurisdictions (Bechky, 2003). Indeed, the notion of boundary evokes coordination problems and breakdowns in understanding that can occur inside and outside the organization. This has been observed during the working group on documents. An affective relationship to the document is demonstrated by each department. These documents are actually the representation of the work of the departments. These kinds of affective attachments are really hard to move. They materialize the strength of the divides between the different trades. A negotiation exercise is therefore required to effectively accomplish collective activities. This articulation work is crucial, in particular during crisis periods. The question of who takes responsibility for it however has to do with issues linked to legitimacy.

6.2.5.3 *Boundary objects*

The example of the quality board presented in chapter 5 questions the definition of the boundary object. The quality board presents intrinsic qualities of boundary objects, like availability, simplicity, flexibility, and reliability. But as explained by (Star and Ruhleder, 2001), the board become a boundary object for people in practice, i.e. in problem-solving situations, when it enables people from different departments to work together without previous consensus. Practices will structure around the board, what will enable collaboration.

The study of this board also shows limits of the concept of boundary object. Without animation around the board, its boundary dimension is reduced. Despite its institutionalized form, the weekly quality meeting around the board, as well as the crisis meeting in case of a major problem do not happen if the animator is not present. This questions the animated dimension of the object, for efficient use of the object.

6.2.6 Conclusion

This section has presented the implementation and the evaluation of the organization dispositions presented in chapter 5 to foster resilience and transversality in problem-solving situations. These methods aimed at shifting an organizational resilience relying only on astute individuals acting as boundary spanners, toward more reliable organizational mechanisms. These mechanisms proved to be efficient in the studied company but this efficiency clearly depends on the implementation methods. First of all, full management support is required to convince the employees to adhere to the new methods. Then, the transformation has to be done step by step, and with employee involvement. Finally, this study showed that transboundary coordination or collaboration is not natural and has to be framed and supported by a neutral and legitimate actor.

By comparing similar dispositions in two different companies, this section gives insight into success factors in their implementation. It also analyses reasons for failures of certain initiatives like the working group on documents.

6.3 Evaluation of the research project

As described in chapter 4.3 reliability and validity of the research project have to be evaluated on different aspects: construct validity, internal validity, external validity and reliability. Discussion on these concepts regarding this dissertation is given in the following sections.

6.3.1 Construct validity

The first issue to consider in evaluating the validity of the research is the construct validity. It is the extent to which correct operational measures were established for the concept being studied. Recommendations to ensure construct validity is to use multiple sources of evidence, and to have key informants review draft case study reports.

Multiple data collection methods were systematically used in the different stages of the case studies. Thanks to the involvement in the company under study, data could be collected through direct observations and full access to data was possible. This data was systematically clarified by experts. Data collected during interviews were systematically triangulated with other interviews or with factual data.

Moreover, findings were presented regularly to the industrial partners, during the steering committees every four months, but also during management and service meetings. These presentations allowed discussion on the data collected and on the findings.

However, difficulties were encountered when trying to quantify the findings. The different propositions made to avoid non-conformity propagation are part of a larger quality and continuous improvement system, which was moreover moving very fast due to the lean transformation over the studied period. The benefits of one single measure are thus difficult if not impossible to quantify. For example, non-conformity costs decreased by 40% between 2010 and 2011, but this is the result of the quantity of measures implemented at that time. Evaluation of the propositions is then done in a more qualitative way often based on the perceptions of the participants.

6.3.2 Internal validity

Internal validity represents the extent to which conjectured relationships actually exist.

Nevertheless, the researcher involvement in the company can induce a bias linked to its proximity with the participants or to its operational responsibilities, which could have threatened the objectivity of its observations. However, to reduce this bias, observations were systematically presented to co-researchers external to the company. Moreover, insight of the literature was systematically sought to validate the findings. However, very few works have been retrieved on the low-volume context. Finally, findings were presented to researcher fellows during international conferences. These exchanges were very helpful in gaining a better knowledge of actual research in quality management and resilience.

6.3.3 External validity

External validity is the extent to which findings can be generalized beyond the immediate case study.

In order to evaluate the generalizability of the findings, a case study was conducted in another industrial context of high volume and high variability. This enables one to discuss the possible effect of industrial context on the results.

Nevertheless more cases would have been needed to fully assess the external validity.

6.3.4 Reliability

Reliability is the extent to which a study can be repeated with the same results. Use of research protocols is advised by (Voss et al., 2002) to ensure reliability in case research. The different stages of the case research as well as detailed protocols are given in the dissertation. Observation guides, interview guides and questionnaires are also presented to give the reader all the necessary material to understand the approach adopted in this work. Furthermore, data was methodically recorded and structured in case databases, from which extractions are given.

CHAPTER 7 CONCLUSION

This chapter returns to the major results obtained in the research work presented here. It first presents the contribution of an interdisciplinary approach to quality research in the low-volume manufacturing field. Then it highlights its contribution to the resilience field and shows how this concept can be transposed from industrial safety to industrial quality. Finally it provides perspectives for further research.

7.1 Major contributions

7.1.1 The interdisciplinary approach

The first contribution that this work makes lies in the interdisciplinary approach adopted to tackle the issue of non-conformity propagation. This transversal research aimed at enriching the engineering field of quality control performance with the organizational dimension of reliability and resilience. These two perspectives have fed each other throughout the project. The concept of non-conformity propagation has actually emerged from the study of the formal and informal management of quality issues. The development propagation tool has taken into account the existence of informal control. The findings from the propagation tool have systematically been analysed in the light of the organisational resilience. Recommendations for practitioners also reflect this concern for a global view. The propagation tool itself could be a transboundary tool aimed at fostering exchanges between departments and transboundary cooperation in problem solving situations. Moreover, this work is aimed at addressing this question from an applied research approach, i.e. in the perspective of theory building and managerial relevance for practitioners.

7.1.2 Relevance of the propagation tool

Industrial companies set up mechanisms to protect themselves against non-conformities: on one hand, risk analyses are put in place to prevent defects and, on the other hand, detection systems are in place in order to detect them as soon as they occur. These measures can however contain breaches allowing some defects to slip through and propagate. This propagation may lead to huge costs for companies because it creates scraps, a need to rework, stress, accident, delays and potentially product recalls which dramatically impact customer satisfaction.

This work is interested in getting this propagation under control, in order to enhance the global performance of the control system and thus the reliability of the delivered products. It proposes two improvement tools to master this propagation. First at the event level a propagation control chart is created and improvement actions are implemented as soon as a propagation threshold is surpassed. Then at the system level, a propagation matrix inventories the defects over a given time period which highlights the permeability of the whole detection system. The interest of this method has been illustrated through case studies in two industries. The method is a decision-aid tool for quality teams, complementary to classical root cause analyses. It helps these teams directing improvement efforts toward weaknesses in the protection system. Actions put in place aim at reinforcing protection mechanisms to avoid internal and external non-conformity propagation. The second case study showed that the tool can also be relevant in a high volume context and that it can be automated when data on quality problems is available.

7.1.3 Relevance of the proposed organizational dispositions

This work has proposed and evaluated a set of organizational dispositions to foster resilience and transversality in problem solving, among which include the implementation of the Lean Manufacturing philosophy, and associated lean training, the use of shop floor management techniques and interdisciplinary working groups and finally, the use of boundary spanners and boundary objects. All the proposed organizational methods aim at improving organizational resilience by rearticulating tasks and making sense of the positioning of one task in relation to the next. This section proposes to return to the extension of the resilience concept in the industrial quality field, to the different forms of resilience based on rectifications and to the cost of resilience.

7.1.3.1 *Resilience in the industrial quality field*

Although mainly theorized as a practice for handling crisis and accidental situations, resilience may be a suitable management practice in non-emergency situations as well. It can be particularly useful in managing day-to-day uncertain situations, or what we call “accumulative” crisis, as encountered by companies in the low volume field, which face even more disruptions than others, for which exhaustive risk analyses are not relevant and for which flexibility and adaptation are key requirements in conducting business.

As in the safety field, companies are regularly confronted with non-conformities that can not be avoided and that propagate. We really saw an opportunity to develop this concept of organizational resilience in the field of industrial quality. It could be seen as the ability of an organization to cope with disruptions in its daily activities (altering process or product quality), to rectify defects to avoid major issues and to maintain an acceptable level of quality in spite of quality issues and crisis. Considering resilience as a strategic concept for management of quality risks and improvement of quality in complex manufacturing systems could be a way to balance the notions of performance and quality.

7.1.3.2 *Different forms of resilience*

The work presented in this dissertation highlights three kinds of resilience based on rectifications, which do not refer to the same involvement of actors. In the second company the production line is resilient, in the sense that in spite of a high level of non-conformities, defect-free products are delivered to customers. This is enabled by a redundant line, with two rework workstations. The quality issues are delegated to the specific workstations, which implies a high specialization of tasks. This type of resilience requires less involvement of actors for which quality issues are not relevant.

The first company is resilient too, in the sense that many non-conformities are rectified informally and do not propagate outside of the company. This type of resilience relies on an "improvised" management of errors and on the high level of competencies of actors as well as on their high quality commitment visible in the rectification process. This work aims at fostering a third type of resilience based on a problem solving network. It is undertaken and supported by the organization who creates negotiation areas and ensures backup processes. Like the second type of resilience presented above, it relies on the involvement of actors but aims at involving more actors and at fostering cooperation and reactivity.

7.1.3.3 *The "cost" of resilience*

The different forms of rectification and resilience, presented in the previous subsection have to be evaluated on the basis of their long-term efficiency and the implied human and organizational costs.

These rectifications have an economic cost for the companies in terms of parts and manpower hours for rework. This resilience may not be sustainable in the long term. In the second company, the production line already experienced limits in this practice, because it is not able to increase the delivery quantities although it would be necessary to satisfy increasing customer demands.

In addition to these economical costs, both cases illustrate the human costs related to resilience, in terms of loss of the sense of work, fatigue, and disengagement. In the first company it is the cost of a resilience mainly relying on individuals, particularly on team leaders, who informally rectify a major part of occurring defects. This form of resilience presents limits in terms of individual overwork and can even be counterproductive. Finally the third form of resilience proposed in this work also presents limits. This kind of parallel organization is costly to manage and to keep alive, particularly in the case where an actor leaves. Organizations should consider these different costs in choosing one of these solutions.

7.2 Perspectives

Several perspectives can be outlined from the work presented here. Firstly, concerning the propagation tool presented in this dissertation, developments have to be conducted to refine this method and to more precisely evaluate the impact of the improvement actions on the control system:

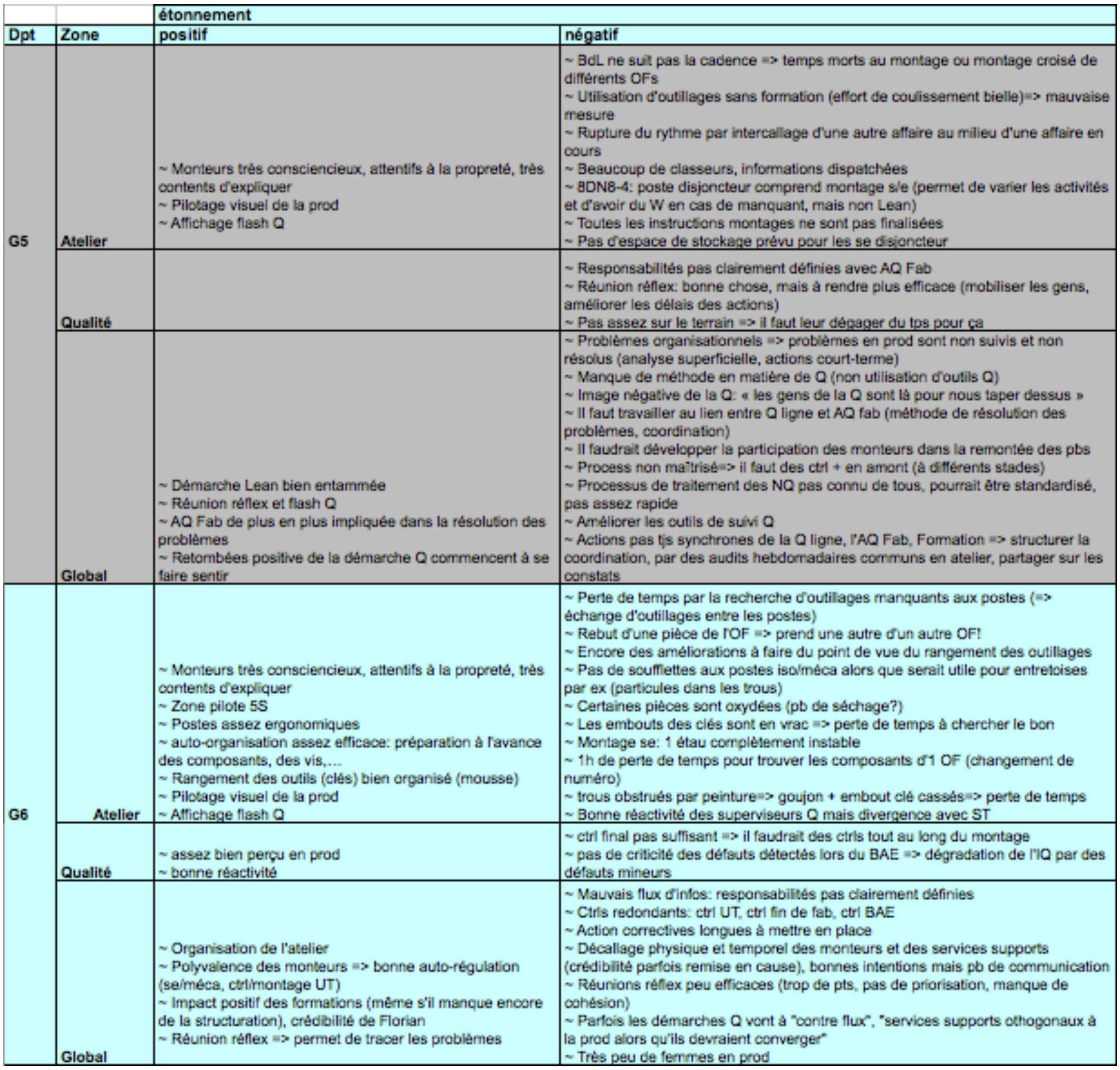
- First of all, some parameters of the proposed propagation model have to be studied and tuned to more efficient action plans. Our propagation and permeability indicators are based on a propagation distance calculated in process steps. This measure has been chosen in order to fit to the breakdown of the assembly process. Other measures could however be used. We quickly eliminated a time measure, which would have been too sensitive to waiting periods (WIP, equipment downtime, etc.). Another possibility that could be investigated is a value-added indicator, which could be measured for example in terms of value of parts and manpower hours that are added to the product. Moreover, the model does not take into account the positioning of the detection location in the process. A development could be to add a criticality factor in the propagation rating, in order to take into account the increasing risk of external propagation, when detection is moving toward the end of the process. This work on the performance of protection systems could be linked to the work by (Bettayeb et al., 2010) on the planning of controls. The concept of propagation could be used to refine the positioning of controls for a given propagation scheme.
- Secondly, the real time implementation of the propagation tool could be conducted on a broader timeframe. The studied timeframe was actually too short to evaluate the impact of the method and the link between propagation and non-conformity costs.
- The applicability of this method in other industries should also be validated. The tool was implemented and automated in a second industrial context, but more cases are needed to achieve generalizability. Other companies in the low-volume field should be investigated, for example in the aerospace field. This implementation will highlight other challenges for improvement of the tool. Then an implementation of these concepts could also be conducted in the service industry. A parallel could be drawn with the healthcare field, which is also characterized by high stakes and safety issues linked to problems in the patient care that could have harmful impact in case of non-detection.
- A last proposition is to extend the control of the propagation to upstream stages in the production process, for example design, purchase and logistics. It may be a good instrument to highlight transboundary risks and to feed continuous improvement to interdisciplinary working groups.

Secondly, regarding the concept of transboundary risks and resilience, further research could also be conducted:

- The topic of organizational resilience in manufacturing, and particularly in the quality field has been studied much less, whereas an opportunity exists to use this concept to improve industrial performance. Further research is needed to examine resilience mechanisms in manufacturing setting and to link these mechanisms to industrial performance.
- Another research avenue is the study of the "over-vigilance" risk associated with resilience. Whereas many works have focused on the bright side of resilience, this work presents some limits of its applicability, particularly in terms of actor overflowing. Other works would enable researchers to investigate further this relationship between resilience and actor being submerged in the case of other "accumulative" crisis.
- Finally, this work illustrates the issues related to documents. As explained by (Tillement, 2011) documents are often at the heart of discussions around risks. Documents refer to trade issues. They move from a trade to the other and are meant to play a coordination role but they often fail in this boundary spanning function and can even be confusing. A research avenue exists to study in an interdisciplinary approach what makes these objects inoperative and how they could be transformed into boundary objects.

CHAPTER 8 APPENDIX

8.1 Appendix I: Summary interviews first exploratory study (extract)

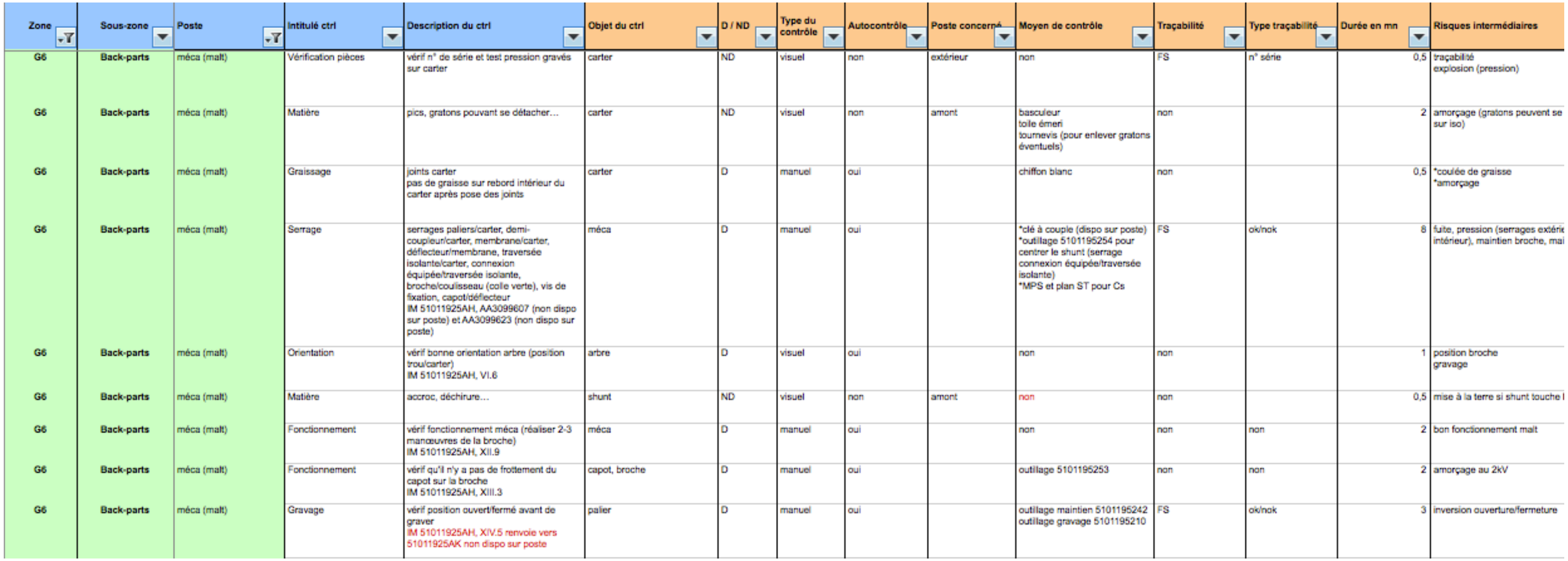


		étonnement	
Dpt	**Zone**	**positif**	**négatif**
G5	**Atelier**	~ Monteurs très consciencieux, attentifs à la propreté, très contents d'expliquer ~ Pilotage visuel de la prod ~ Affichage flash Q	~ BdL ne suit pas la cadence => temps morts au montage ou montage croisé de différents OFs ~ Utilisation d'outillages sans formation (effort de coulissement bielle)=> mauvaise mesure ~ Rupture du rythme par intercallage d'une autre affaire au milieu d'une affaire en cours ~ Beaucoup de classeurs, informations dispatchées ~ 8DN8-4: poste disjoncteur comprend montage s/e (permet de varier les activités et d'avoir du W en cas de manquant, mais non Lean) ~ Toutes les instructions montages ne sont pas finalisées ~ Pas d'espace de stockage prévu pour les se disjoncteur
	Qualité		~ Responsabilités pas clairement définies avec AQ Fab ~ Réunion réflex: bonne chose, mais à rendre plus efficace (mobiliser les gens, améliorer les délais des actions) ~ Pas assez sur le terrain => il faut leur dégager du tps pour ça
	Global	~ Démarche Lean bien entammée ~ Réunion réflex et flash Q ~ AQ Fab de plus en plus impliquée dans la résolution des problèmes ~ Retombées positive de la démarche Q commencent à se faire sentir	~ Problèmes organisationnels => problèmes en prod sont non suivis et non résolus (analyse superficielle, actions court-terme) ~ Manque de méthode en matière de Q (non utilisation d'outils Q) ~ Image négative de la Q: « les gens de la Q sont là pour nous taper dessus » ~ Il faut travailler au lien entre Q ligne et AQ fab (méthode de résolution des problèmes, coordination) ~ Il faudrait développer la participation des monteurs dans la remontée des pbs ~ Process non maîtrisé=> il faut des ctrl + en amont (à différents stades) ~ Processus de traitement des NQ pas connu de tous, pourrait être standardisé, pas assez rapide ~ Améliorer les outils de suivi Q ~ Actions pas tjs synchrones de la Q ligne, l'AQ Fab, Formation => structurer la coordination, par des audits hebdomadaires communs en atelier, partager sur les constats
G6	**Atelier**	~ Monteurs très consciencieux, attentifs à la propreté, très contents d'expliquer ~ Zone pilote 5S ~ Postes assez ergonomiques ~ auto-organisation assez efficace: préparation à l'avance des composants, des vis,… ~ Rangement des outils (clés) bien organisé (mousse) ~ Pilotage visuel de la prod ~ Affichage flash Q	~ Perte de temps par la recherche d'outillages manquants aux postes (=> échange d'outillages entre les postes) ~ Rebut d'une pièce de l'OF => prend une autre d'un autre OF! ~ Encore des améliorations à faire du point de vue du rangement des outillages ~ Pas de soufflettes aux postes iso/méca alors que serait utile pour entretoises par ex (particules dans les trous) ~ Certaines pièces sont oxydées (pb de séchage?) ~ Les embouts des clés sont en vrac => perte de temps à chercher le bon ~ Montage se: 1 étau complètement instable ~ 1h de perte de temps pour trouver les composants d'1 OF (changement de numéro) ~ trous obstrués par peinture=> goujon + embout clé cassés=> perte de temps ~ Bonne réactivité des superviseurs Q mais divergence avec ST
	Qualité	~ assez bien perçu en prod ~ bonne réactivité	~ ctrl final pas suffisant => il faudrait des ctrls tout au long du montage ~ pas de criticité des défauts détectés lors du BAE => dégradation de l'IQ par des défauts mineurs
	Global	~ Organisation de l'atelier ~ Polyvalence des monteurs => bonne auto-régulation (se/méca, ctrl/montage UT) ~ Impact positif des formations (même s'il manque encore de la structuration), crédibilité de Florian ~ Réunion réflex => permet de tracer les problèmes	~ Mauvais flux d'infos: responsabilités pas clairement définies ~ Ctrls redondants: ctrl UT, ctrl fin de fab, ctrl BAE ~ Action correctives longues à mettre en place ~ Décallage physique et temporel des monteurs et des services supports (crédibilité parfois remise en cause), bonnes intentions mais pb de communication ~ Réunions réflex peu efficaces (trop de pts, pas de priorisation, manque de cohésion) ~ Parfois les démarches Q vont à "contre flux", "services supports othogonaux à la prod alors qu'ils devraient converger" ~ Très peu de femmes en prod

8.2 Appendix II: Questionnaire quality controls

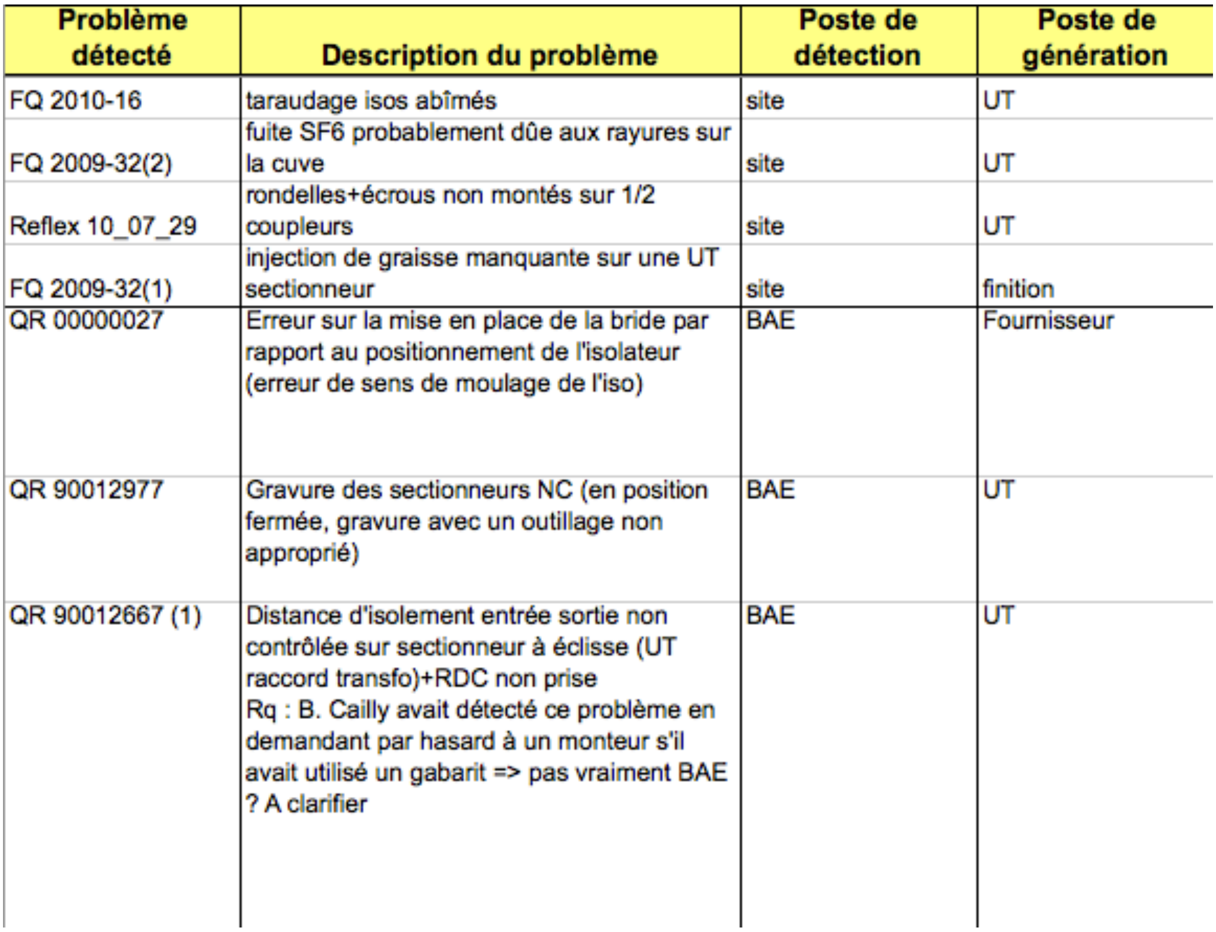
Questions	**Détail**
Etape	situation dans le process
Contrôle	n° instruction de montage si formalisé
Type de contrôle et description	demandé / non demandé + autocontrôle + ok/nok, visuel, dimensionnel… demandé = formalisé par écrit
Objet	pièce, sous-ensemble, outillage, matière… ce qui est contrôlé
Moyen de contrôle	machine et/ou opérateur, superviseur qualité, équipements de test spécifiques...
Fréquence du contrôle	combien de fois par jour ou par semaine
Traçabilité	''non'' ou lieu/document d'enregistrement : fiche suiveuse, plan, informatique (attention aux double-saisies)
Durée du contrôle	
Risques couverts	
VA du contrôle	incertitude avant / après, à déterminer avec le service Assurance Qualité Produit
Echantillon contrôlé	100% ou pas ?
% de rejet	
Action en cas de rejet	réparation sur poste, retour en amont, rebut, dérogation service technique…
Encours moyen avant contrôle	
Attente avant test/contrôle	attente du contrôleur
Evaluation par le monteur/ contrôleur/ superviseur de la pertinence du contrôle	
Le contrôle peut-il être occulté ? Dans quelles conditions ?	pour analyse ultérieure (pas pour les monteurs)
Commentaires	

8.3 Appendix III: Database quality controls



Zone	Sous-zone	Poste	Intitulé ctrl	Description du ctrl	Objet du ctrl	D / ND	Type du contrôle	Autocontrôle	Poste concerné	Moyen de contrôle	Traçabilité	Type traçabilité	Durée en mn	Risques intermédiaires
G6	Back-parts	méca (malt)	Vérification pièces	vérif n° de série et test pression gravés sur carter	carter	ND	visuel	non	extérieur	non	FS	n° série	0,5	traçabilité explosion (pression)
G6	Back-parts	méca (malt)	Matière	pics, gratons pouvant se détacher…	carter	ND	visuel	non	amont	basculeur toile émeri tournevis (pour enlever gratons éventuels)	non		2	amorçage (gratons peuvent se sur iso)
G6	Back-parts	méca (malt)	Graissage	joints carter pas de graisse sur rebord intérieur du carter après pose des joints	carter	D	manuel	oui		chiffon blanc	non		0,5	*coulée de graisse *amorçage
G6	Back-parts	méca (malt)	Serrage	serrages paliers/carter, demi-coupleur/carter, membrane/carter, déflecteur/membrane, traversée isolante/carter, connexion équipée/traversée isolante, broche/coulisseau (colle verte), vis de fixation, capot/déflecteur IM 51011925AH, AA3099607 (non dispo sur poste) et AA3099623 (non dispo sur poste)	méca	D	manuel	oui		*clé à couple (dispo sur poste) *outillage 5101195254 pour centrer le shunt (serrage connexion équipée/traversée isolante) *MPS et plan ST pour Cs	FS	ok/nok	8	fuite, pression (serrages extérie intérieur), maintien broche, mai
G6	Back-parts	méca (malt)	Orientation	vérif bonne orientation arbre (position trou/carter) IM 51011925AH, VI.6	arbre	D	visuel	oui		non	non		1	position broche gravage
G6	Back-parts	méca (malt)	Matière	accroc, déchirure…	shunt	ND	visuel	non	amont	non	non		0,5	mise à la terre si shunt touche
G6	Back-parts	méca (malt)	Fonctionnement	vérif fonctionnement méca (réaliser 2-3 manœuvres de la broche) IM 51011925AH, XII.9	méca	D	manuel	oui		non	non	non	2	bon fonctionnement malt
G6	Back-parts	méca (malt)	Fonctionnement	vérif qu'il n'y a pas de frottement du capot sur la broche IM 51011925AH, XIII.3	capot, broche	D	manuel	oui		outillage 5101195253	non	non	2	amorçage au 2kV
G6	Back-parts	méca (malt)	Gravage	vérif position ouvert/fermé avant de graver IM 51011925AH, XIV.5 renvoie vers 51011925AK non dispo sur poste	palier	D	manuel	oui		outillage maintien 5101195242 outillage gravage 5101195210	FS	ok/nok	3	inversion ouverture/fermeture

8.4 Appendix IV: Database non-conformities



Problème détecté	Description du problème	Poste de détection	Poste de génération
FQ 2010-16	taraudage isos abîmés	site	UT
FQ 2009-32(2)	fuite SF6 probablement dûe aux rayures sur la cuve	site	UT
Reflex 10_07_29	rondelles+écrous non montés sur 1/2 coupleurs	site	UT
FQ 2009-32(1)	injection de graisse manquante sur une UT sectionneur	site	finition
QR 00000027	Erreur sur la mise en place de la bride par rapport au positionnement de l'isolateur (erreur de sens de moulage de l'iso)	BAE	Fournisseur
QR 90012977	Gravure des sectionneurs NC (en position fermée, gravure avec un outillage non approprié)	BAE	UT
QR 90012667 (1)	Distance d'isolement entrée sortie non contrôlée sur sectionneur à éclisse (UT raccord transfo)+RDC non prise Rq : B. Cailly avait détecté ce problème en demandant par hasard à un monteur s'il avait utilisé un gabarit => pas vraiment BAE ? A clarifier	BAE	UT

8.5 Appendix V: Lean questionnaire

1. **Qu’est-ce que le Lean pour vous ?**

2. **Connaissez-vous au moins 1 outil du Lean ?**

OUI	NON

Si oui, lequel ?

3. **Est-ce que le terme SPS est parlant pour vous ?**

Très	Assez	Peu	Pas du tout

4. **Que vous évoque le terme SPS ?**

5. **Pouvez- vous citer 3 des 7 gaspillages ?**

- …………………….
- …………………….
- …………………….

6. **Pensez-vous pouvoir appliquer certains principes du Lean dans votre zone de travail ?**

OUI	NON

Si oui, lesquels?

8.6 Appendix VI: Instruction for management of non-conformity

Processus de Traitement des non-conformités détectées AVANT livraison sur site du matériel

1) BUT

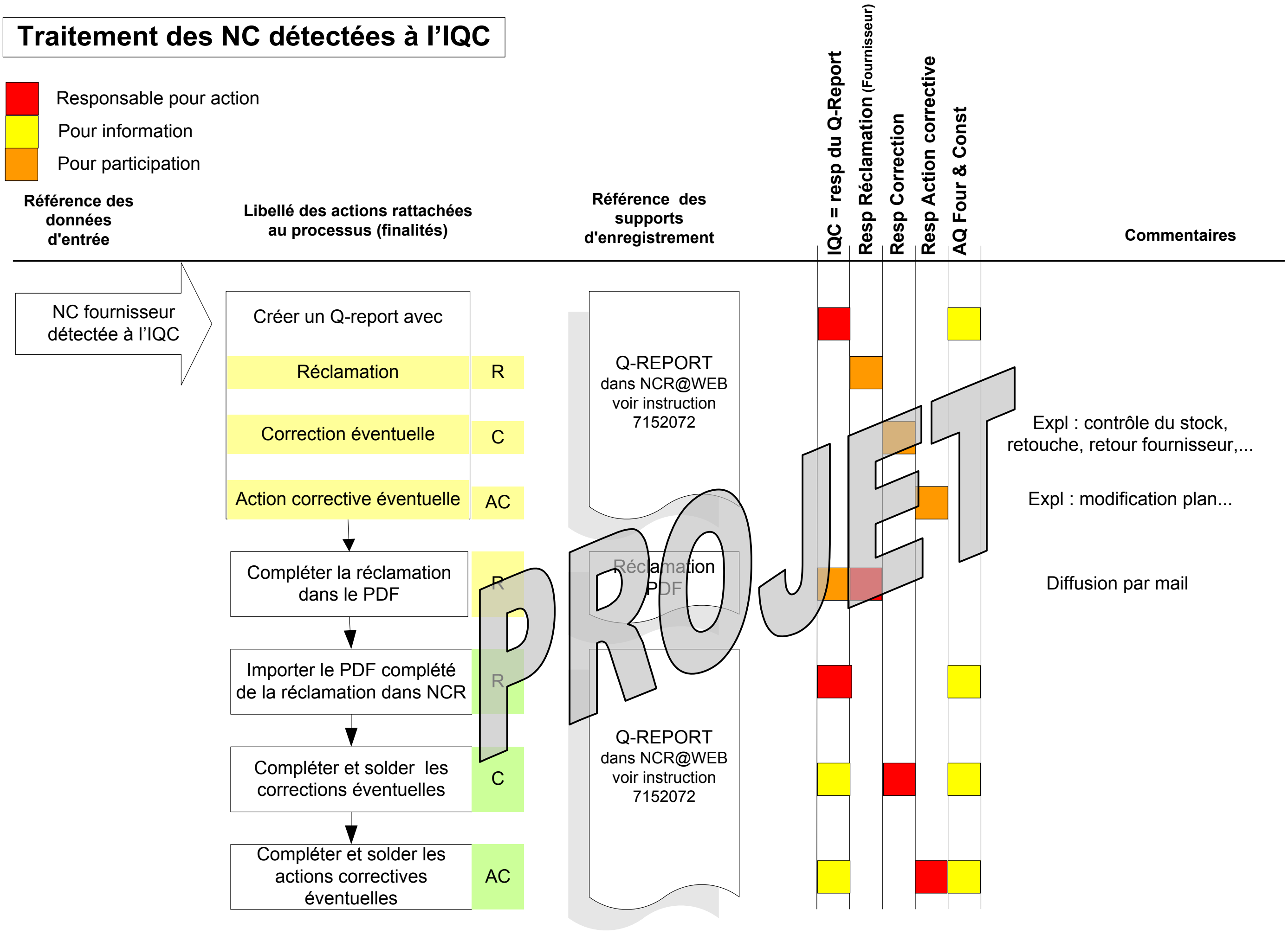
Décrire le processus de traitement des non-conformités détectées avant livraison : réalisation d'un Q-Report dans l'outil NCR@Web.

2) DOMAINE D'APPLICATION

Cette instruction s'applique à toute non-conformité détectée sur les lignes de préfabrication ou montage (non conformités constituants, impossibilité ou erreur de montage, erreur de mise en œuvre des essais qui nécessite la reprise du matériel testé ou résultats de tests hors tolérances).

3) RESPONSABILITES ET MODALITES GENERALES

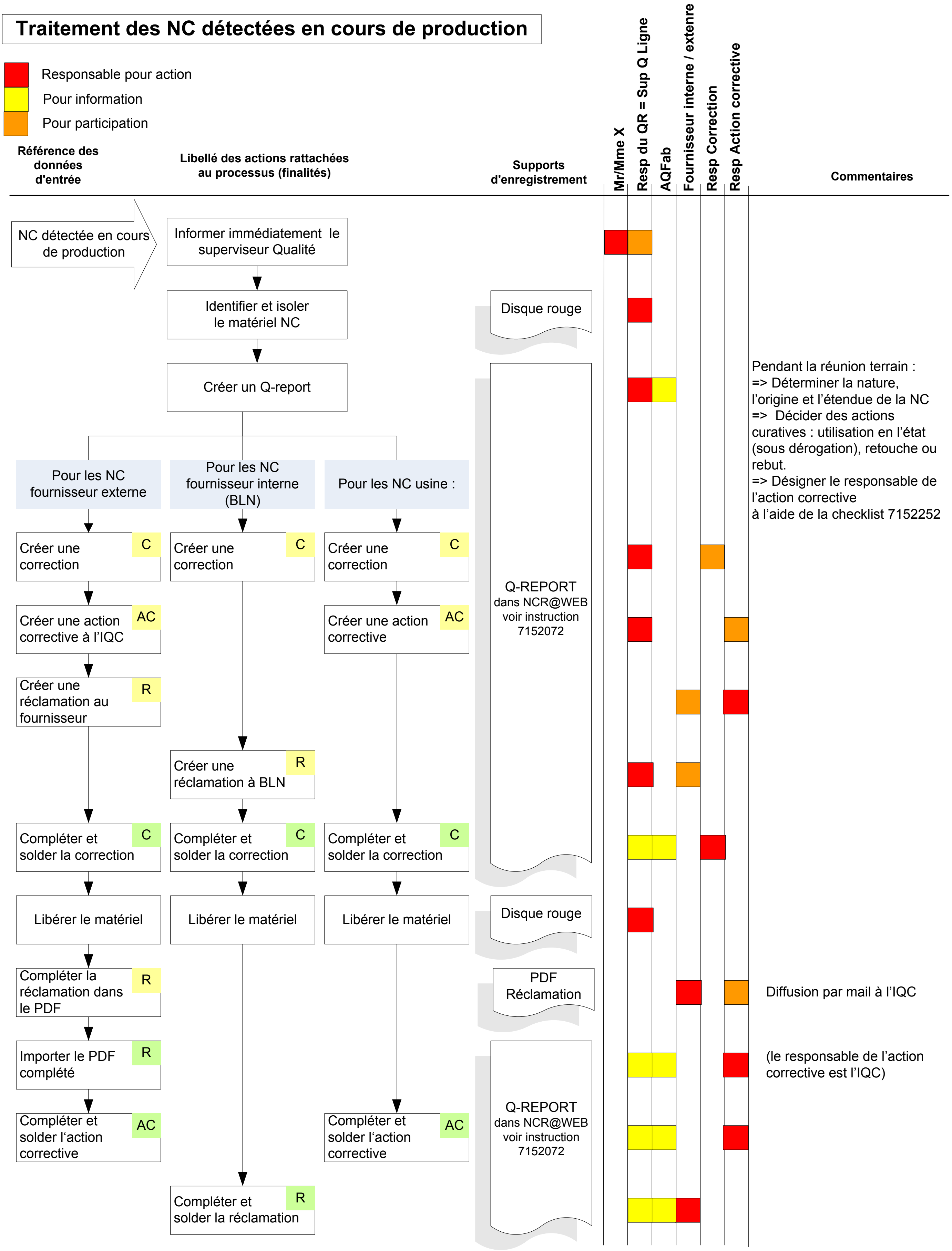
Le traitement d'un Q-Report est décrit dans les logigrammes suivants.



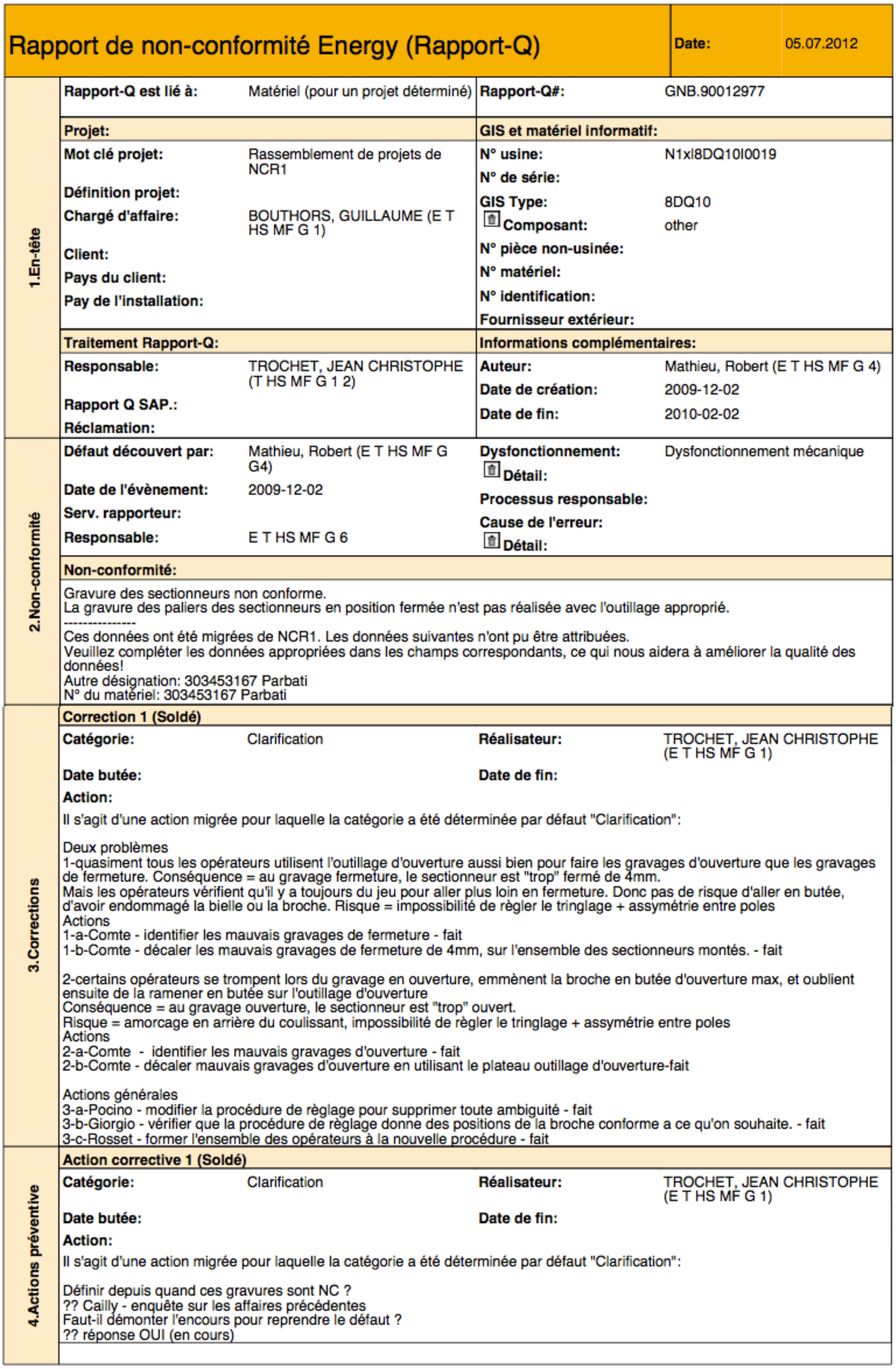
Traitement des NC détectées à l'IQC

🟥 Responsable pour action
🟨 Pour information
🟧 Pour participation

Référence des données d'entrée	Libellé des actions rattachées au processus (finalités)		Référence des supports d'enregistrement	IQC = resp du Q-Report	Resp Réclamation (Fournisseur)	Resp Correction	Resp Action corrective	AQ Four & Const	Commentaires
NC fournisseur détectée à l'IQC	Créer un Q-report avec		Q-REPORT dans NCR@WEB voir instruction 7152072	🟥				🟨	
	Réclamation	R			🟧				
	Correction éventuelle	C				🟧			Expl : contrôle du stock, retouche, retour fournisseur,...
	Action corrective éventuelle	AC					🟧		Expl : modification plan...
	Compléter la réclamation dans le PDF	R	Réclamation PDF	🟧	🟥				Diffusion par mail
	Importer le PDF complété de la réclamation dans NCR	R	Q-REPORT dans NCR@WEB voir instruction 7152072	🟥				🟨	
	Compléter et solder les corrections éventuelles	C		🟨		🟥		🟨	
	Compléter et solder les actions correctives éventuelles	AC		🟨			🟥	🟨	


Traitement des NC détectées en cours de production
Responsable pour action
Pour information
Pour participation
Référence des données d'entrée
Libellé des actions rattachées au processus (finalités)
Supports d'enregistrement
Mr/Mme X
Resp du QR = Sup Q Ligne
AQFab
Fournisseur interne / externe
Resp Correction
Resp Action corrective
Commentaires
NC détectée en cours de production
Informer immédiatement le superviseur Qualité
Identifier et isoler le matériel NC
Disque rouge
Créer un Q-report
Pendant la réunion terrain :
=> Déterminer la nature, l'origine et l'étendue de la NC
=> Décider des actions curatives : utilisation en l'état (sous dérogation), retouche ou rebut.
=> Désigner le responsable de l'action corrective
à l'aide de la checklist 7152252
Pour les NC fournisseur externe
Pour les NC fournisseur interne (BLN)
Pour les NC usine :
Créer une correction
C
Créer une action corrective à l'IQC
AC
Créer une action corrective
Créer une réclamation au fournisseur
R
Créer une réclamation à BLN
Q-REPORT dans NCR@WEB voir instruction 7152072
Compléter et solder la correction
Libérer le matériel
Disque rouge
Compléter la réclamation dans le PDF
PDF Réclamation
Diffusion par mail à l'IQC
Importer le PDF complété
(le responsable de l'action corrective est l'IQC)
Compléter et solder l'action corrective
Q-REPORT dans NCR@WEB voir instruction 7152072
Compléter et solder la réclamation

8.7 Appendix VII: Non-conformity report



Rapport de non-conformité Energy (Rapport-Q)		**Date:**	05.07.2012

1.En-tête

Rapport-Q est lié à:	Matériel (pour un projet déterminé)	**Rapport-Q#:**	GNB.90012977
Projet:		**GIS et matériel informatif:**	
Mot clé projet:	Rassemblement de projets de NCR1	**N° usine:**	N1xl8DQ10l0019
Définition projet:		**N° de série:**	
Chargé d'affaire:	BOUTHORS, GUILLAUME (E T HS MF G 1)	**GIS Type:**	8DQ10
		Composant:	other
Client:		**N° pièce non-usinée:**	
Pays du client:		**N° matériel:**	
Pay de l'installation:		**N° identification:**	
		Fournisseur extérieur:	
Traitement Rapport-Q:		**Informations complémentaires:**	
Responsable:	TROCHET, JEAN CHRISTOPHE (T HS MF G 1 2)	**Auteur:**	Mathieu, Robert (E T HS MF G 4)
		Date de création:	2009-12-02
Rapport Q SAP.:		**Date de fin:**	2010-02-02
Réclamation:			

2.Non-conformité

Défaut découvert par:	Mathieu, Robert (E T HS MF G G4)	**Dysfonctionnement:**	Dysfonctionnement mécanique
		Détail:	
Date de l'évènement:	2009-12-02	**Processus responsable:**	
Serv. rapporteur:		**Cause de l'erreur:**	
Responsable:	E T HS MF G 6	**Détail:**	

Non-conformité:

Gravure des sectionneurs non conforme.
La gravure des paliers des sectionneurs en position fermée n'est pas réalisée avec l'outillage approprié.

Ces données ont été migrées de NCR1. Les données suivantes n'ont pu être attribuées.
Veuillez compléter les données appropriées dans les champs correspondants, ce qui nous aidera à améliorer la qualité des données!
Autre désignation: 303453167 Parbati
N° du matériel: 303453167 Parbati

3.Corrections

Correction 1 (Soldé)

Catégorie:	Clarification	**Réalisateur:**	TROCHET, JEAN CHRISTOPHE (E T HS MF G 1)
Date butée:		**Date de fin:**	

Action:

Il s'agit d'une action migrée pour laquelle la catégorie a été déterminée par défaut "Clarification":

Deux problèmes
1-quasiment tous les opérateurs utilisent l'outillage d'ouverture aussi bien pour faire les gravages d'ouverture que les gravages de fermeture. Conséquence = au gravage fermeture, le sectionneur est "trop" fermé de 4mm.
Mais les opérateurs vérifient qu'il y a toujours du jeu pour aller plus loin en fermeture. Donc pas de risque d'aller en butée, d'avoir endommagé la bielle ou la broche. Risque = impossibilité de règler le tringlage + assymétrie entre poles
Actions
1-a-Comte - identifier les mauvais gravages de fermeture - fait
1-b-Comte - décaler les mauvais gravages de fermeture de 4mm, sur l'ensemble des sectionneurs montés. - fait

2-certains opérateurs se trompent lors du gravage en ouverture, emmènent la broche en butée d'ouverture max, et oublient ensuite de la ramener en butée sur l'outillage d'ouverture
Conséquence = au gravage ouverture, le sectionneur est "trop" ouvert.
Risque = amorcage en arrière du coulissant, impossibilité de règler le tringlage + assymétrie entre poles
Actions
2-a-Comte - identifier les mauvais gravages d'ouverture - fait
2-b-Comte - décaler mauvais gravages d'ouverture en utilisant le plateau outillage d'ouverture-fait

Actions générales
3-a-Pocino - modifier la procédure de règlage pour supprimer toute ambiguité - fait
3-b-Giorgio - vérifier que la procédure de règlage donne des positions de la broche conforme a ce qu'on souhaite. - fait
3-c-Rosset - former l'ensemble des opérateurs à la nouvelle procédure - fait

4.Actions préventive

Action corrective 1 (Soldé)

Catégorie:	Clarification	**Réalisateur:**	TROCHET, JEAN CHRISTOPHE (E T HS MF G 1)
Date butée:		**Date de fin:**	

Action:

Il s'agit d'une action migrée pour laquelle la catégorie a été déterminée par défaut "Clarification":

Définir depuis quand ces gravures sont NC ?
?? Cailly - enquête sur les affaires précédentes
Faut-il démonter l'encours pour reprendre le défaut ?
?? réponse OUI (en cours)

8.8 Appendix VIII: Use of the automated propagation tool in Siemens I A SC

This is an extract of the instruction for the use of the automated propagation tool developed in Siemens I A SC.

Chapitre 1. Installation et paramétrage

1. INSTALLATION INITIALE

Le fichier analyse propagation est installé sur le réseau à l'adresse suivante :

P:\Qm_Work\Q-PROCESSUS\PS11\02_PROJETS QUALITE\2_QUALITE PROCESSUS\04_PROCESSUS_LIGNE_FINALE\Propagation.xls

Il fait appelle à la base de donnée des erreurs de la ligne finale PI 1 extraite de SAP qui se trouve également sur le réseau :

P:\Qm_Work\Q-PROCESSUS\PS11\02_PROJETS QUALITE\2_QUALITE PROCESSUS\04_PROCESSUS_LIGNE_FINALE\Suivi des réparation du 01.07.2010 .xls"

2. PARAMETRAGE

A l'ouverture du fichier, Activer les macros

Pour pouvoir faire le lien avec la base des erreurs, il faut renseigner le chemin d'accès de la base dans la macro VBA. Pour ce faire :

3. Ouvrir l'éditeur VBA : touches Alt+F11

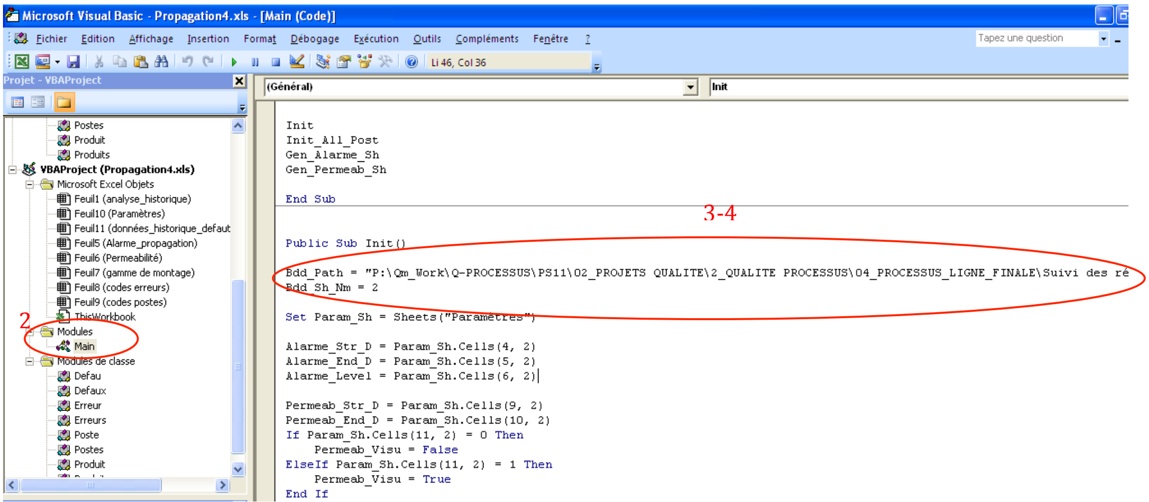
4. Ouvrir le module Main : double-cliquer sur Main dans la fenètre de gauche (projet VBA)

5. Renseigner le chemin d'accès de la base

   Bdd_Path = « nom_du_fichier_base.xls »

6. Renseigner la position de l'onglet désiré dans le fichier base de données

   Bdd_Sh_Nm = 1 (si l'onglet utilisé est le premier du fichier base, etc.)



```
Init
Init_All_Post
Gen_Alarme_Sh
Gen_Permeab_Sh

End Sub


Public Sub Init()

Bdd_Path = "P:\Qm_Work\Q-PROCESSUS\PS11\02_PROJETS QUALITE\2_QUALITE PROCESSUS\04_PROCESSUS_LIGNE_FINALE\Suivi des ré
Bdd_Sh_Nm = 2

Set Param_Sh = Sheets("Paramètres")

Alarme_Str_D = Param_Sh.Cells(4, 2)
Alarme_End_D = Param_Sh.Cells(5, 2)
Alarme_Level = Param_Sh.Cells(6, 2)

Permeab_Str_D = Param_Sh.Cells(9, 2)
Permeab_End_D = Param_Sh.Cells(10, 2)
If Param_Sh.Cells(11, 2) = 0 Then
    Permeab_Visu = False
ElseIf Param_Sh.Cells(11, 2) = 1 Then
    Permeab_Visu = True
End If
```

Chapitre 2. Utilisation de l'outil

1. INTRODUCTION

L'outil comporte 2 parties :

7. Alarmes propagation

Cette analyse permet de recenser les défauts qui se sont propagés au-delà d'un certain seuil, sur une période donnée.

8. Analyse perméabilité

Cette analyse permet de recenser par poste les défauts générés, détectés et les détections loupées sur une période donnée.

2. ONGLET PARAMETRES

Les cases jaunes sont à renseigner avant de démarrer l'analyse.

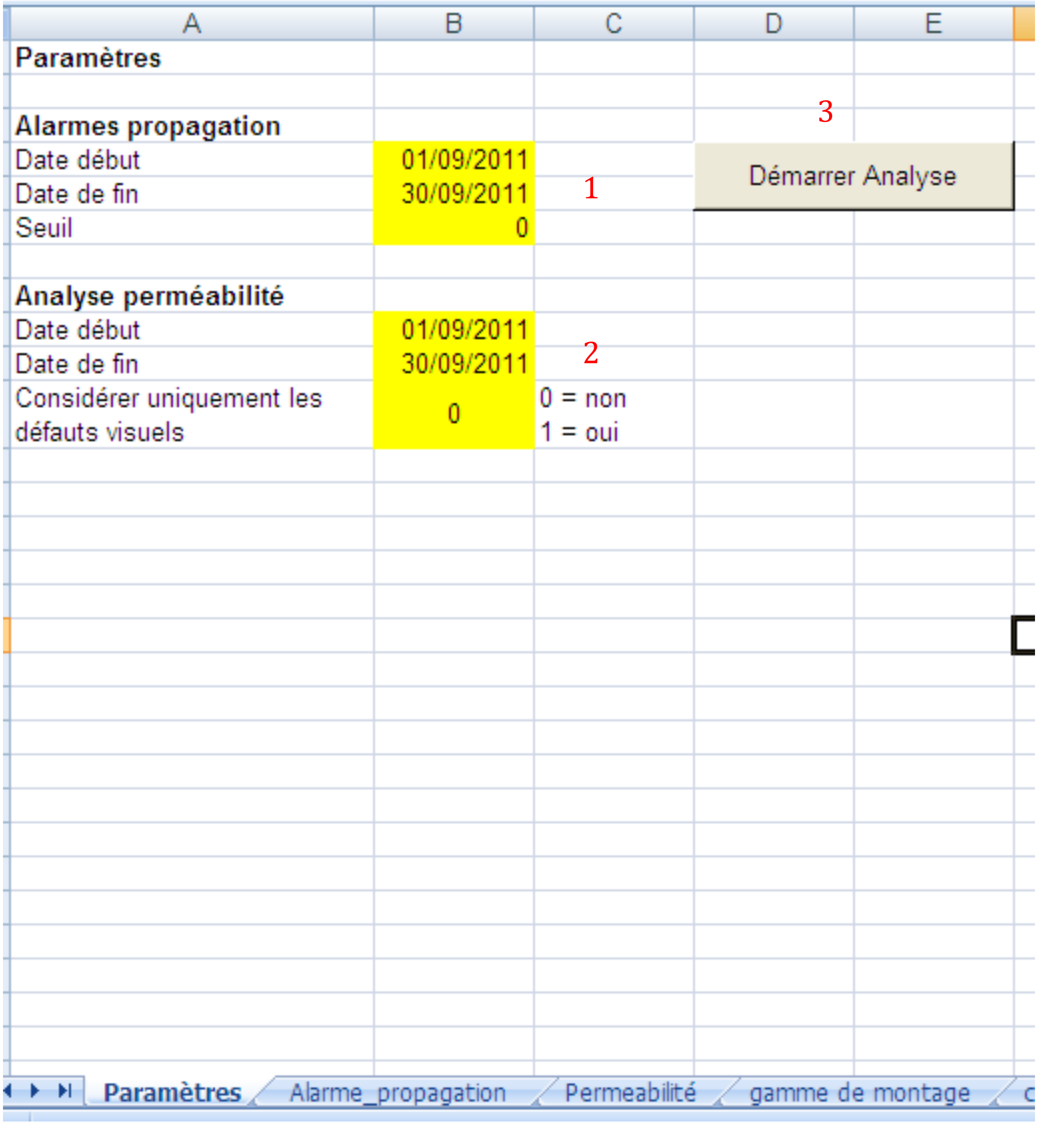
1. Pour la partie alarme propagation :
- Date de début d'analyse : format JJ/MM/AAAA
- Date de fin d'analyse : format JJ/MM/AAAA
- Seuil : nombre d'étape de propagation à partir duquel on déclenche une alarme

2. Pour la partie analyse perméabilité :
- Date de début d'analyse : format JJ/MM/AAAA
- Date de fin d'analyse : format JJ/MM/AAAA
- Considérer uniquement les défauts visuels : 1 = oui, 0=non

3. Une fois ces paramètres renseignés, appuyer sur le bouton « Démarrer » pour lancer l'analyse.

4. Activer les macros si besoin

5. Mettre à jour le fichier si besoin



A	B	C	D	E
Paramètres				
Alarmes propagation				
Date début	01/09/2011			
Date de fin	30/09/2011			
Seuil	0			
Analyse perméabilité				
Date début	01/09/2011			
Date de fin	30/09/2011			
Considérer uniquement les défauts visuels	0	0 = non 1 = oui		

Avis de sécurité Microsoft Office Excel

Microsoft Office a identifié un problème de sécurité potentiel.

Avertissement : il est impossible de vérifier que ce contenu provient d'une source fiable. À moins qu'il offre des fonctionnalités importantes et que vous approuviez sa source, laissez-le désactivé.

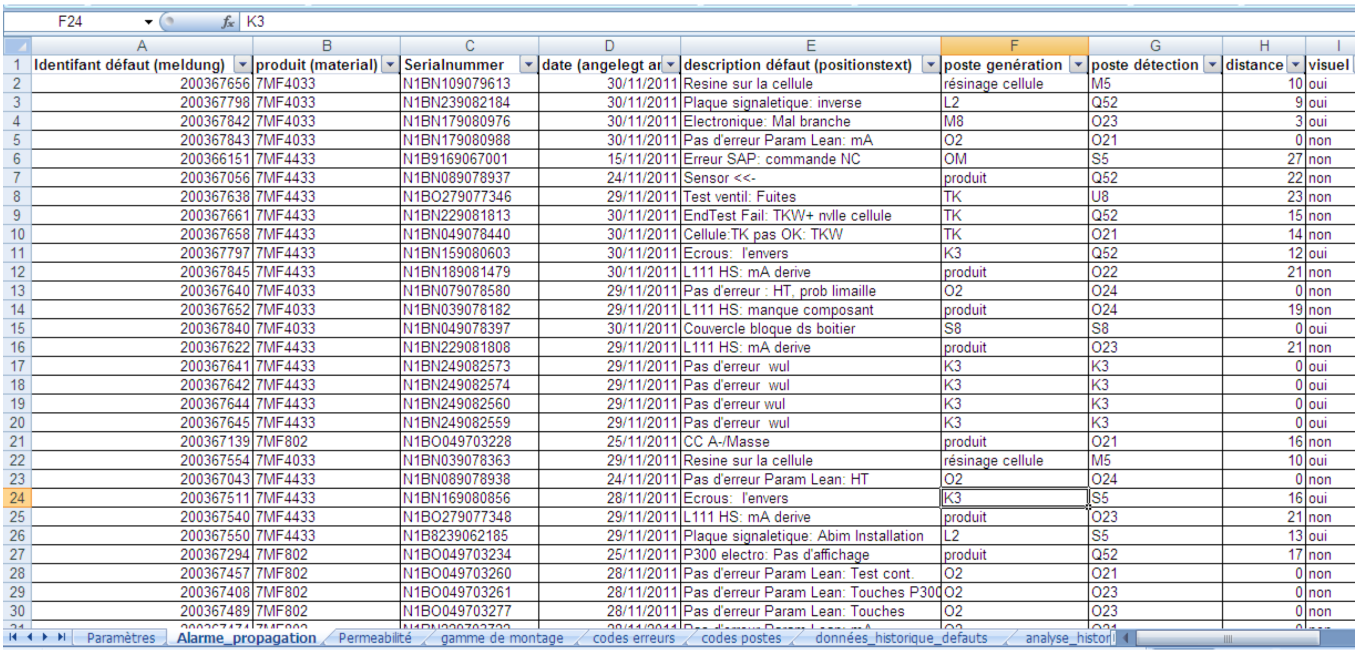
Chemin d'accès au fichier : D:\...opie de Suivi des réparation du 01 07 2010 .xls

Les macros ont été désactivées. Les macros peuvent contenir des virus ou d'autres dangers pour la sécurité. N'activez pas ce contenu, sauf si vous êtes certain que la source du fichier est fiable.

9. ALARMES PROPAGATION

Le deuxième onglet recense les défauts et leur propagation sur une période donnée.

Les colonnes sont les suivantes :
- Identifiant du défaut : correspond au Qm-Auftrag
- Produit : référence matériel défectueux
- Serialnummer : numéro de série de l'appareil défectueux
- Date : date de l'enregistrement du défaut
- Description du défaut
- Poste génération : origine du défaut
- Poste détection : détection du défaut
- Distance : distance de propagation du défaut en nombre d'étape dans le processus de fabrication
- Visuel : le défaut est-il visuel (oui) ou non

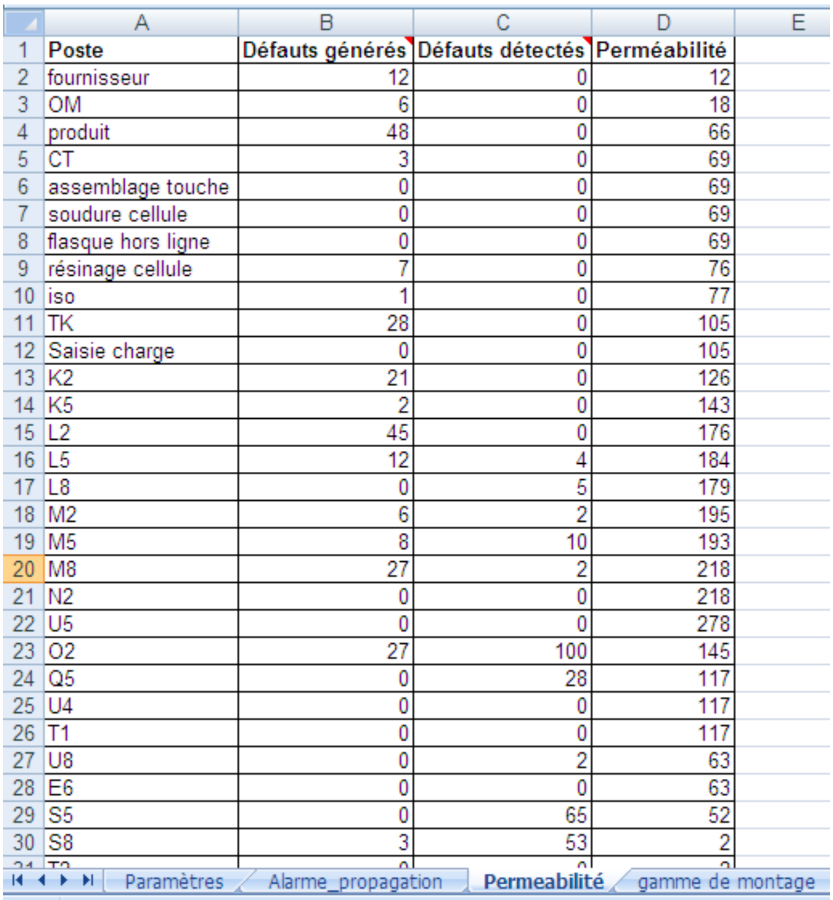


	A	B	C	D	E	F	G	H	I
1	Identifant défaut (meldung)	produit (material)	Serialnummer	date (angelegt ar	description défaut (positionstext)	poste genération	poste détection	distance	visuel
2	200367656	7MF4033	N1BN109079613	30/11/2011	Resine sur la cellule	résinage cellule	M5	10	oui
3	200367798	7MF4033	N1BN239082184	30/11/2011	Plaque signaletique: inverse	L2	Q52	9	oui
4	200367842	7MF4033	N1BN179080976	30/11/2011	Electronique: Mal branche	M8	O23	3	oui
5	200367843	7MF4033	N1BN179080988	30/11/2011	Pas d'erreur Param Lean: mA	O2	O21	0	non
6	200366151	7MF4433	N1B9169067001	15/11/2011	Erreur SAP: commande NC	OM	S5	27	non
7	200367056	7MF4433	N1BN089078937	24/11/2011	Sensor <<-	produit	Q52	22	non
8	200367638	7MF4433	N1BO279077346	29/11/2011	Test ventil: Fuites	TK	U8	23	non
9	200367661	7MF4433	N1BN229081813	30/11/2011	EndTest Fail: TKW+ nvlle cellule	TK	Q52	15	non
10	200367658	7MF4433	N1BN049078440	30/11/2011	Cellule:TK pas OK: TKW	TK	O21	14	non
11	200367797	7MF4433	N1BN159080603	30/11/2011	Ecrous: l'envers	K3	Q52	12	oui
12	200367845	7MF4433	N1BN189081479	30/11/2011	L111 HS: mA derive	produit	O22	21	non
13	200367640	7MF4033	N1BN079078580	29/11/2011	Pas d'erreur : HT, prob limaille	O2	O24	0	non
14	200367652	7MF4033	N1BN039078182	29/11/2011	L111 HS: manque composant	produit	O24	19	non
15	200367840	7MF4033	N1BN049078397	30/11/2011	Couvercle bloque ds boitier	S8	S8	0	oui
16	200367622	7MF4433	N1BN229081808	29/11/2011	L111 HS: mA derive	produit	O23	21	non
17	200367641	7MF4433	N1BN249082573	29/11/2011	Pas d'erreur wul	K3	K3	0	oui
18	200367642	7MF4433	N1BN249082574	29/11/2011	Pas d'erreur wul	K3	K3	0	oui
19	200367644	7MF4433	N1BN249082560	29/11/2011	Pas d'erreur wul	K3	K3	0	oui
20	200367645	7MF4433	N1BN249082559	29/11/2011	Pas d'erreur wul	K3	K3	0	oui
21	200367139	7MF802	N1BO049703228	25/11/2011	CC A-/Masse	produit	O21	16	non
22	200367554	7MF4033	N1BN039078363	29/11/2011	Resine sur la cellule	résinage cellule	M5	10	oui
23	200367043	7MF4433	N1BN089078938	24/11/2011	Pas d'erreur Param Lean: HT	O2	O24	0	non
24	200367511	7MF4433	N1BN169080856	28/11/2011	Ecrous: l'envers	K3	S5	16	oui
25	200367540	7MF4433	N1BO279077348	29/11/2011	L111 HS: mA derive	produit	O23	21	non
26	200367550	7MF4433	N1B8239062185	29/11/2011	Plaque signaletique: Abim Installation	L2	S5	13	oui
27	200367294	7MF802	N1BO049703234	25/11/2011	P300 electro: Pas d'affichage	produit	Q52	17	non
28	200367457	7MF802	N1BO049703260	28/11/2011	Pas d'erreur Param Lean: Test cont.	O2	O21	0	non
29	200367408	7MF802	N1BO049703261	28/11/2011	Pas d'erreur Param Lean: Touches P300	O2	O23	0	non
30	200367489	7MF802	N1BO049703277	28/11/2011	Pas d'erreur Param Lean: Touches	O2	O23	0	non

10. ANALYSE DE PERMEABILITE

Cette analyse permet de recenser par poste les défauts générés, détectés et les détections loupées sur une période donnée.

Les colonnes sont les suivantes :
- Poste : nom du poste
- Défauts générés : nombre de défauts générés à ce poste sur la période demandée
- Défauts détectés : nombre de défauts détectés à ce poste sur la période demandée
- Perméabilité : nombre de détections loupées à ce poste sur la période donnée

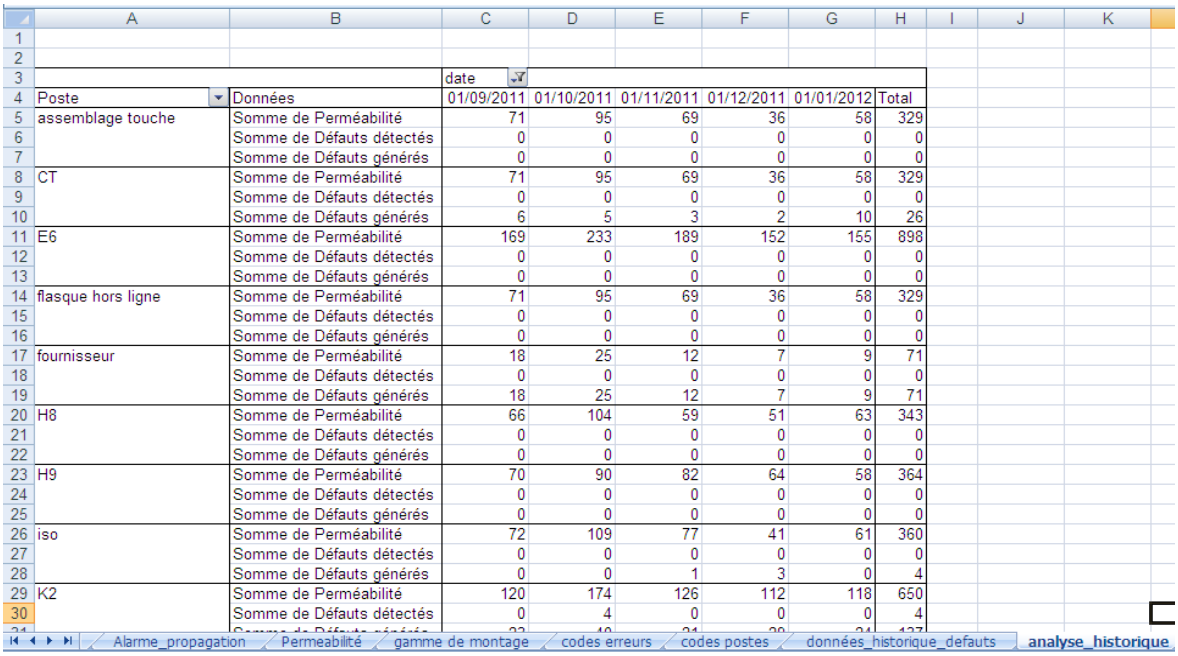


Poste	Défauts générés	Défauts détectés	Perméabilité
fournisseur	12	0	12
OM	6	0	18
produit	48	0	66
CT	3	0	69
assemblage touche	0	0	69
soudure cellule	0	0	69
flasque hors ligne	0	0	69
résinage cellule	7	0	76
iso	1	0	77
TK	28	0	105
Saisie charge	0	0	105
K2	21	0	126
K5	2	0	143
L2	45	0	176
L5	12	4	184
L8	0	5	179
M2	6	2	195
M5	8	10	193
M8	27	2	218
N2	0	0	218
U5	0	0	278
O2	27	100	145
Q5	0	28	117
U4	0	0	117
T1	0	0	117
U8	0	2	63
E6	0	0	63
S5	0	65	52
S8	3	53	2

11. HISTORIQUE

A la fin de chaque mois, recopier les données de l'analyse de perméabilité du mois dans l'onglet Données_historique-défauts, à la suite des données existante.

Cela complète automatiquement le tableau croisé dynamique dans l'onglet analyse_historique.
Cet onglet permet de visualiser l'évolution dans le temps des générations, détections et perméabilités par poste.

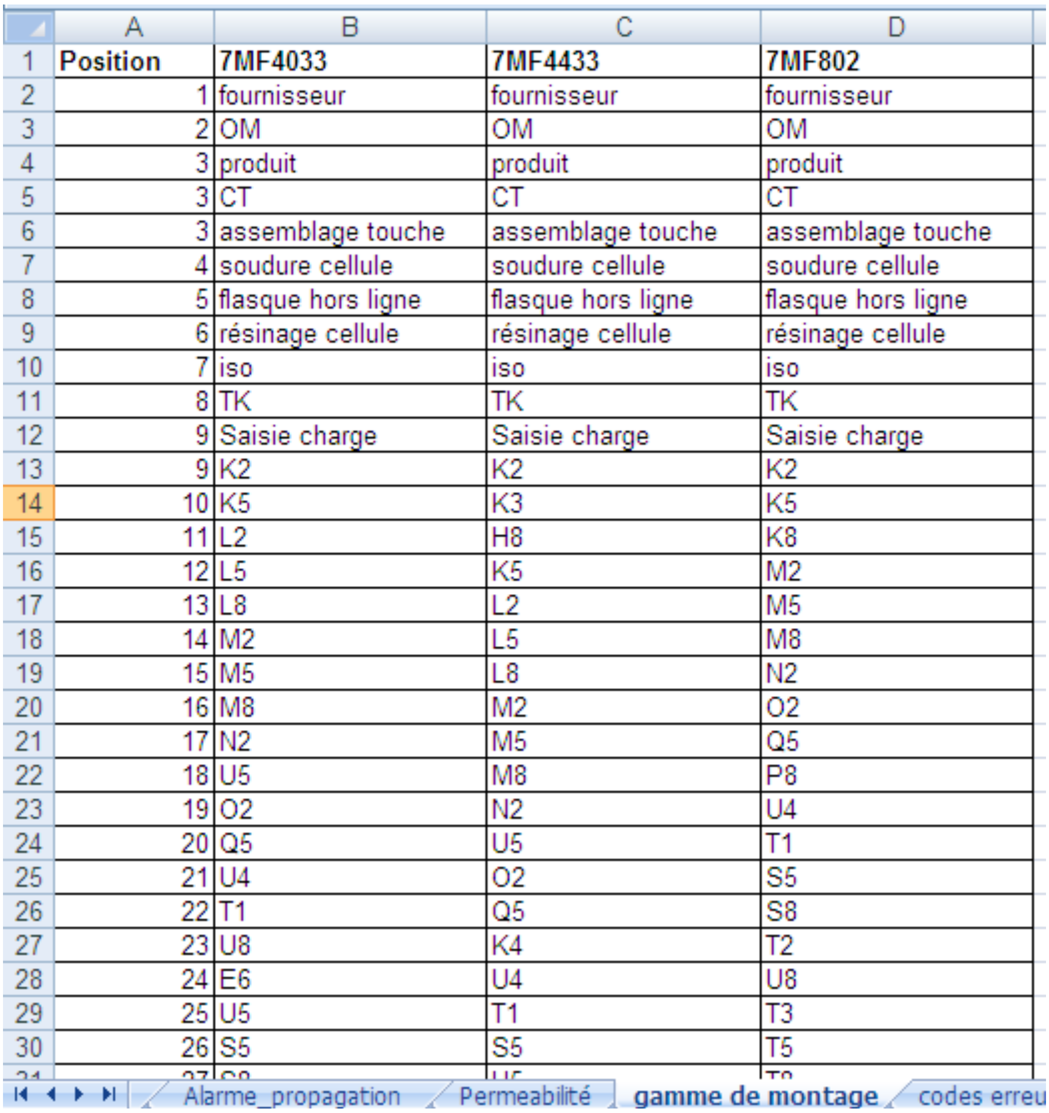


		date					
Poste	Données	01/09/2011	01/10/2011	01/11/2011	01/12/2011	01/01/2012	Total
assemblage touche	Somme de Perméabilité	71	95	69	36	58	329
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	0	0	0	0	0	0
CT	Somme de Perméabilité	71	95	69	36	58	329
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	6	5	3	2	10	26
E6	Somme de Perméabilité	169	233	189	152	155	898
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	0	0	0	0	0	0
flasque hors ligne	Somme de Perméabilité	71	95	69	36	58	329
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	0	0	0	0	0	0
fournisseur	Somme de Perméabilité	18	25	12	7	9	71
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	18	25	12	7	9	71
H8	Somme de Perméabilité	66	104	59	51	63	343
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	0	0	0	0	0	0
H9	Somme de Perméabilité	70	90	82	64	58	364
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	0	0	0	0	0	0
iso	Somme de Perméabilité	72	109	77	41	61	360
	Somme de Défauts détectés	0	0	0	0	0	0
	Somme de Défauts générés	0	0	1	3	0	4
K2	Somme de Perméabilité	120	174	126	112	118	650
	Somme de Défauts détectés	0	4	0	0	0	4

Chapitre 3. Maintenance de l’outil

12. GAMMES DE MONTAGE

Le calcul de la distance de propagation est basé sur les gammes de montage des produits (onglet « gamme de montage »).
La gamme décrit pour chaque produit l’enchainement des étapes de fabrication.
La première colonne « position » correspond au numéro de l’étape. Deux étapes en parallèle ont la même position dans la gamme de montage.



	A	B	C	D
1	**Position**	**7MF4033**	**7MF4433**	**7MF802**
2	1	fournisseur	fournisseur	fournisseur
3	2	OM	OM	OM
4	3	produit	produit	produit
5	3	CT	CT	CT
6	3	assemblage touche	assemblage touche	assemblage touche
7	4	soudure cellule	soudure cellule	soudure cellule
8	5	flasque hors ligne	flasque hors ligne	flasque hors ligne
9	6	résinage cellule	résinage cellule	résinage cellule
10	7	iso	iso	iso
11	8	TK	TK	TK
12	9	Saisie charge	Saisie charge	Saisie charge
13	9	K2	K2	K2
14	10	K5	K3	K5
15	11	L2	H8	K8
16	12	L5	K5	M2
17	13	L8	L2	M5
18	14	M2	L5	M8
19	15	M5	L8	N2
20	16	M8	M2	O2
21	17	N2	M5	Q5
22	18	U5	M8	P8
23	19	O2	N2	U4
24	20	Q5	U5	T1
25	21	U4	O2	S5
26	22	T1	Q5	S8
27	23	U8	K4	T2
28	24	E6	U4	U8
29	25	U5	T1	T3
30	26	S5	S5	T5

i. Modification d’une gamme

Il est possible de modifier directement la gamme de montage d’un produit en effaçant ou rajoutant une étape ou en modifiant le nom d’une étape.

ii. Ajout d'une gamme

Pour ajouter une gamme de produit, ajouter une colonne suivant le modèle existant : en première ligne le nom du produit suivi par les étapes successives de fabrication.

13. CODES ERREURS

L'identification des postes de génération des défauts dans l'analyse de la propagation et de la perméabilité est basée sur la correspondance entre les codes erreurs et les postes d'origine.

Cette correspondance se trouve dans l'onglet « codes erreurs »

Pour chaque erreur la colonne C indique si le défaut est visuel ou non.

Il est possible de modifier la liste des codes erreurs

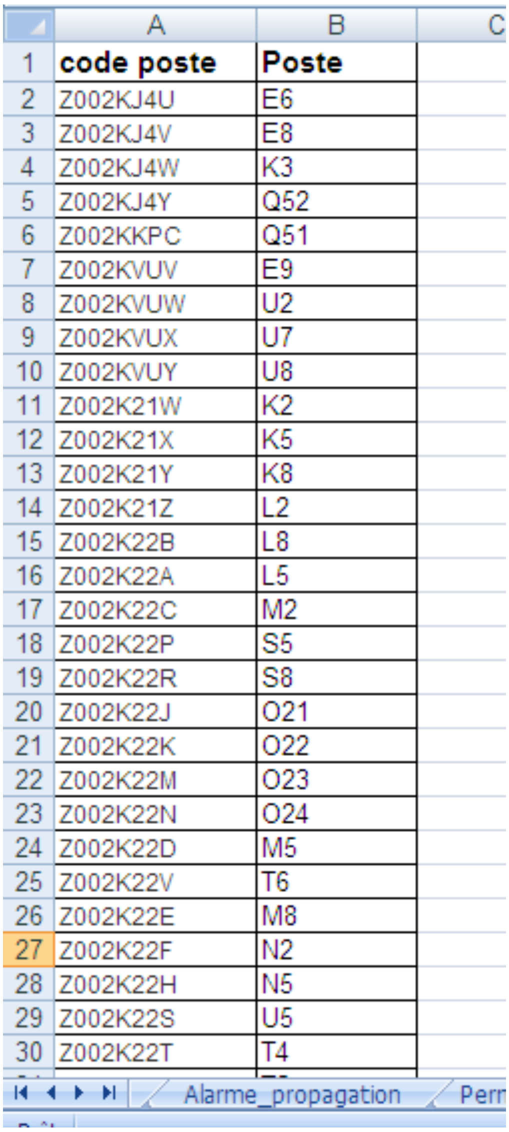
- Ajout/ suppression d'un code : ajouter ou supprimer une ligne
- Modification du poste d'origine
- Modification de l'attribut visuel

	A	B	C
1	**Code erreur**	**Poste d'origine**	**Visuel**
2	PS11LE-AA01-P60-REP1-Limande abimee:Meca	M5	oui
3	PS11LE-AA01-P60-REP1-Limande dechiree:Meca	M5	oui
4	PS11LE-AA01-P60-REP1-Limande dechiree:Pb position resine	résinage cellule	oui
5	PS11LE-AA01-P60-REP1-limande arrachee: Meca	M5	oui
6	PS11LE-AA03-P33-Rep1-limande arrachee: Meca soudure NUG	E6	oui
7	PS11LE-AA01-P60-REP1-limande arrachee: Pb position resine	résinage cellule	oui
8	PS11LE-AA02-P60-REP1-Oeillets decolles/abimes:Meca	M5	oui
9	PS11LE-AA02-P60-REP1-Œillets decolles/abimes:Soudure/desou	M5	oui
10	PS11LE-BA01-P70-RP60-CC A-/Masse	produit	non
11	PS11LE-BA01-P70-RP60-CC A+/Masse	produit	non
12	PS11LE-BA01-P70-RP60-CC E-/Masse	produit	non
13	PS11LE-BA01-P70-RP60-CC E+/Masse	produit	non
14	PS11LE-BA01-P70-RP60-CC S/Masse	produit	non
15	PS11LE-BA02-P70-RP60-CC T/Masse	produit	non
16	PS11LE-BA03-P70-RP60-CC L114-3/Masse (Afficheur)	produit	non
17	PS11LE-BA04-P70-RP60-CC L111-7/Masse (EMV DS3)	produit	non
18	PS11LE-BA04-P70-RP60-CC B8/Masse (EMV PA)	produit	non
19	PS11LE-CA01-P70-RP60-## A-	produit	non
20	PS11LE-CA01-P70-RP60-## A+	produit	non
21	PS11LE-CA01-P70-RP60-## E-	produit	non
22	PS11LE-CA01-P70-RP60-## E+	produit	non
23	PS11LE-CA01-P70-RP60-Sensor >>+	produit	non
24	PS11LE-CA01-P70-RP60-Sensor <<-	produit	non
25	PS11LE-CA02-P70-RP60-Sensor ##	produit	non
26	PS11LE-CA02-P70-RP60-CC A+/E+	produit	non
27	PS11LE-CA02-P70-RP60-CC A-/E-	produit	non
28	PS11LE-CA02-P70-RP60-CC A+/E-	produit	non
29	PS11LE-CA02-P70-RP60-CC A-/E+	produit	non
30	PS11LE-CA02-P70-RP60-CC A+/A-	produit	non

14. CODES POSTES

L’identification des postes de détection des défauts dans l’analyse de perméabilité est basée sur la correspondance entre les codes postes et les postes de détection qui est disponible dans l’onglet « codes postes ».

Il est possible de modifier la liste des codes postes
- Ajout/ suppression d’un code : ajouter ou supprimer une ligne
- Modification d’une correspondance de poste



	A	B	C
1	**code poste**	**Poste**	
2	Z002KJ4U	E6	
3	Z002KJ4V	E8	
4	Z002KJ4W	K3	
5	Z002KJ4Y	Q52	
6	Z002KKPC	Q51	
7	Z002KVUV	E9	
8	Z002KVUW	U2	
9	Z002KVUX	U7	
10	Z002KVUY	U8	
11	Z002K21W	K2	
12	Z002K21X	K5	
13	Z002K21Y	K8	
14	Z002K21Z	L2	
15	Z002K22B	L8	
16	Z002K22A	L5	
17	Z002K22C	M2	
18	Z002K22P	S5	
19	Z002K22R	S8	
20	Z002K22J	O21	
21	Z002K22K	O22	
22	Z002K22M	O23	
23	Z002K22N	O24	
24	Z002K22D	M5	
25	Z002K22V	T6	
26	Z002K22E	M8	
27	Z002K22F	N2	
28	Z002K22H	N5	
29	Z002K22S	U5	
30	Z002K22T	T4	

15. ONGLETS DU FICHIER

Attention : Ne pas modifier le nom des onglets dans le fichier analyse propagation

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CONTROLLING NON-CONFORMITY PROPAGATION IN LOW VOLUME MANUFACTURING

Résumé

Ce travail de thèse propose une approche pluridisciplinaire de la qualité dans les systèmes de production manufacturiers, couplant les approches d'ingénierie et de sociologie des organisations. Il s'intéresse aux risques de non-conformités qui peuvent se propager dans le processus de réalisation et atteindre le client final. Il est basé sur des études de cas réalisées chez Siemens ETHS, une entreprise produisant de faibles quantités de matériel haute-tension hautement personnalisé. Cette étude propose tout d'abord une méthode qualité pour améliorer le système de détection des non-conformités en identifiant et en agissant sur ses faiblesses. Dans une deuxième approche, cette thèse propose des instruments organisationnels pour limiter la propagation des non-conformités entre les frontières organisationnelles et améliorer la résilience de l'organisation face à ces problèmes transfrontières. Les deux approches ont été mises en œuvre dans l'entreprise étudiée puis étendues à une autre entreprise du groupe opérant sur le segment de la production de masse ce qui a permis de tirer des conclusions à la fois académiques et managériales pour les partenaires industriels.

Mots clés

Qualité, Production de faible volume, Propagation, Non-conformités, Transfrontière, Résilience organisationnelle

Abstract

This thesis proposes an interdisciplinary approach of quality in manufacturing production systems that combines quality engineering and organization studies. It is interested in the risk of non-conformities that can propagate in the delivery process and reach the final customer. It builds upon case studies conducted at Siemens ETHS, a company manufacturing low volumes of customized high-voltage equipment. First, a quality methodology is proposed to improve the detection system of non-conformities by identifying its weaknesses and acting on them. A second approach proposes organizational mechanisms to avoid non-conformity propagation between organizational boundaries and improve the organizational resilience in case of transboundary problems. Both approaches have been implemented in the company under study and then extended to another company of the group operating in the high volume field, what enabled the researcher to draw academic conclusions as well as to build practical knowledge for the industrial partners.

Keywords

Quality, Low volume manufacturing, Propagation, Non-conformity, Transboundary, Organizational resilience.